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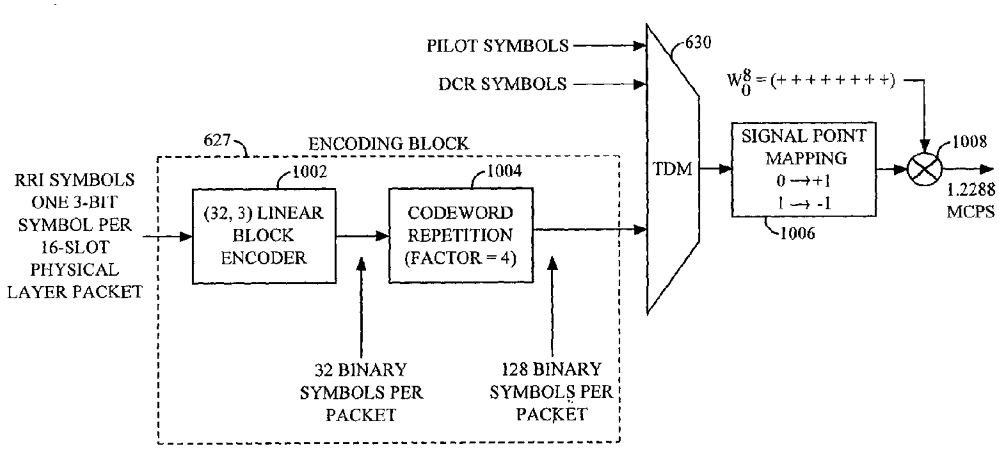
(54) Title: MAXIMUM DISTANCE BLOCK CODING SCHEME



(57) Abstract: In a data communication system capable of variable rate transmission, high rate packet data transmission improves utilization of the forward link and decreases the transmission delay. Data tramission on the forward link is time multiplexed and the base station (4) transmits at the highest data rate supported by the forward link at each time slot to one mobile station (6). The data rate is determined by the largest C/I measurement of the forward link signals as measured at the mobile station (6). Upon determination of a data packet received in error, the mobile station (6) transmits a NACK message back to the base station (4). The NACK message results in retransmission of the data packet received in error. The data packets can be transmitted out of sequence by the use of sequence number to identify each data unit within the data packets. On the reverse link, reverse rate indicator symbols are encoded at the mobile station (6) to achieve a maximum distance between different code words.

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MAXIMUM DISTANCE BLOCK CODING SCHEME

BACKGROUND OF THE INVENTION

I. Field of the Invention

The present invention pertains to data communication, and more particularly to a maximum-distance, rate 3/128 block coding scheme for use in a high-rate packet data communication system.

II. Background

A modern day communication system is required to support a variety of applications. One such communication system is a code division multiple access (CDMA) system which conforms to the "TIA/EIA/IS-95 Mobile Station-Base Station Compatibility Standard for Dual-Mode Wideband Spread Spectrum Cellular System", hereinafter referred to as the IS-95 standard. The CDMA system allows for voice and data communications between users over a terrestrial link. The use of CDMA techniques in a multiple access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS", and U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM", both assigned to the assignee of the present invention and incorporated by reference herein.

In this specification, base station refers to the hardware with which the mobile stations communicate. Cell refers to the hardware or the geographic coverage area, depending on the context in which the term is used. A sector is a partition of a cell. Because a sector of a CDMA system has the attributes of a cell, the teachings described in terms of cells are readily extended to sectors.

In the CDMA system, communications between users are conducted through one or more base stations. A first user on one mobile station communicates to a second user on a second mobile station by transmitting data on the reverse link to a base station. The base station receives the data and can route the data to another base station. The data is transmitted on the forward link of the same base station, or a second base station, to the second mobile station. The forward link refers to transmission from the base station to a

mobile station and the reverse link refers to transmission from the mobile station to a base station. In IS-95 systems, the forward link and the reverse link are allocated separate frequencies.

The mobile station communicates with at least one base station during a communication. CDMA mobile stations are capable of communicating with multiple base stations simultaneously during soft handoff. Soft handoff is the process of establishing a link with a new base station before breaking the link with the previous base station. Soft handoff minimizes the probability of dropped calls. The method and system for providing a communication with a mobile station through more than one base station during the soft handoff process are disclosed in U.S. Patent No. 5,267,261, entitled "MOBILE ASSISTED SOFT HANDOFF IN A CDMA CELLULAR TELEPHONE SYSTEM," assigned to the assignee of the present invention and incorporated by reference herein. Softer handoff is the process whereby the communication occurs over multiple sectors which are serviced by the same base station. The process of softer handoff is described in detail in copending U.S. Patent No. 5,933,787, entitled "METHOD AND APPARATUS FOR PERFORMING HANDOFF BETWEEN SECTORS OF A COMMON BASE STATION", issued August 3, 1999, assigned to the assignee of the present invention and incorporated by reference herein.

Given the growing demand for wireless data applications, the need for very efficient wireless data communication systems has become increasingly significant. The IS-95 standard is capable of transmitting traffic data and voice data over the forward and reverse links. A method for transmitting traffic data in code channel frames of fixed size is described in detail in U.S. Patent No. 5,504,773, entitled "METHOD AND APPARATUS FOR THE FORMATTING OF DATA FOR TRANSMISSION", assigned to the assignee of the present invention and incorporated by reference herein. In accordance with the IS-95 standard, the traffic data or voice data is partitioned into code channel frames which are 20 msec wide with data rates as high as 14.4 Kbps.

A significant difference between voice services and data services is the fact that the former imposes stringent and fixed delay requirements. Typically, the overall one-way delay of speech frames must be less than 100 msec. In contrast, the data delay can become a variable parameter used to optimize the efficiency of the data communication system. Specifically, more efficient error correcting coding techniques which require significantly larger delays than those that can be tolerated by voice services can be utilized. An exemplary efficient coding scheme for data is disclosed in U.S. Patent No. 5,933,462, entitled "SOFT DECISION OUTPUT DECODER FOR DECODING

CONVOLUTIONALLY ENCODED CODEWORDS", issued August 3, 1999, assigned to the assignee of the present invention and incorporated by reference herein.

Another significant difference between voice services and data services is that the former requires a fixed and common grade of service (GOS) for all users. Typically, for digital systems providing voice services, this translates into a fixed and equal transmission rate for all users and a maximum tolerable value for the error rates of the speech frames. In contrast, for data services, the GOS can be different from user to user and can be a parameter optimized to increase the overall efficiency of the data communication system. The GOS of a data communication system is typically defined as the total delay incurred in the transfer of a predetermined amount of data, hereinafter referred to as a data packet.

Yet another significant difference between voice services and data services is that the former requires a reliable communication link which, in the exemplary CDMA communication system, is provided by soft handoff. Soft handoff results in redundant transmissions from two or more base stations to improve reliability. However, this additional reliability is not required for data transmission because the data packets received in error can be retransmitted. For data services, the transmit power used to support soft handoff can be more efficiently used for transmitting additional data.

The parameters that measure the quality and effectiveness of a data communication system are the transmission delay required to transfer a data packet and the average throughput rate of the system. Transmission delay does not have the same impact in data communication as it does for voice communication, but it is an important metric for measuring the quality of the data communication system. The average throughput rate is a measure of the efficiency of the data transmission capability of the communication system.

It is well known that in cellular systems the signal-to-noise-and-interference ratio C/I of any given user is a function of the location of the user within the coverage area. In order to maintain a given level of service, TDMA and FDMA systems resort to frequency reuse techniques, i.e. not all frequency channels and/or time slots are used in each base station. In a CDMA system, the same frequency allocation is reused in every cell of the system, thereby improving the overall efficiency. The C/I that any given user's mobile station achieves determines the information rate that can be supported for this particular link from the base station to the user's mobile station. Given the specific modulation and error correction method used for the transmission,

which the present invention seek to optimize for data transmissions, a given level of performance is achieved at a corresponding level of C/I. For idealized cellular system with hexagonal cell layouts and utilizing a common frequency in every cell, the distribution of C/I achieved within the idealized cells can be calculated.

The C/I achieved by any given user is a function of the path loss, which for terrestrial cellular systems increases as r^3 to r^5, where r is the distance to the radiating source. Furthermore, the path loss is subject to random variations due to man-made or natural obstructions within the path of the radio wave. These random variations are typically modeled as a lognormal shadowing random process with a standard deviation of 8 dB. The resulting C/I distribution achieved for an ideal hexagonal cellular layout with omni-directional base station antennas, r^4 propagation law, and shadowing process with 8 dB standard deviation is shown in Fig. 10.

The obtained C/I distribution can only be achieved if, at any instant in time and at any location, the mobile station is served by the best base station which is defined as that achieving the largest C/I value, regardless of the physical distance to each base station. Because of the random nature of the path loss as described above, the signal with the largest C/I value can be one which is other than the minimum physical distance from the mobile station. In contrast, if a mobile station was to communicate only via the base station of minimum distance, the C/I can be substantially degraded. It is therefore beneficial for mobile stations to communicate to and from the best serving base station at all times, thereby achieving the optimum C/I value. It can also be observed that the range of values of the achieved C/I, in the above idealized model and as shown in FIG. 10, is such that the difference between the highest and lowest value can be as large as 10,000. In practical implementation the range is typically limited to approximately 1:100 or 20 dB. It is therefore possible for a CDMA base station to serve mobile stations with information bit rates that can vary by as much as a factor of 100, since the following relationship holds:

$$R_b = W\frac{(C/I)}{(E_b/I_o)}, \qquad (1)$$

where R_b represents the information rate to a particular mobile station, W is the total bandwidth occupied by the spread spectrum signal, and E_b/I_o is the energy per bit over interference density required to achieve a given level of

performance. For instance, if the spread spectrum signal occupies a bandwidth W of 1.2288 MHz and reliable communication requires an average E_b/I_o equal to 3 dB, then a mobile station which achieves a C/I value of 3 dB to the best base station can communicate at a data rate as high as 1.2288 Mbps. On the other hand, if a mobile station is subject to substantial interference from adjacent base stations and can only achieve a C/I of -7 dB, reliable communication can not be supported at a rate greater than 122.88 Kbps. A communication system designed to optimize the average throughput will therefore attempt to serve each remote user from the best serving base station and at the highest data rate R_b that the remote user can reliably support. It would be advantageous to provide a data communication system that exploits the characteristic cited above and optimizes the data throughput from the CDMA base stations to the mobile stations.

It would further be advantageous to provide a more robust channel for a mobile station to use when indicating the reverse link data rate at which it is transmitting data. In a data communication system, a reverse link data rate indicator is advantageously a relatively "slow" channel, requiring transmission only a fraction of the time that a pilot channel, for example, is transmitted. Currently, a relatively high-rate, orthogonal encoding scheme with repetition is used. It would be desirable to increase the minimum distance (the number of symbols in the encoder output code word that are different) between different encoder output code words in such a coding scheme in order to improve the coding gain. Thus, there is a need for a method of improving coding gains in a high-data-rate communication system.

SUMMARY OF THE INVENTION

The present invention is directed to a method of improving coding gains in a high-data-rate communication system. Accordingly, in one aspect of the invention, a method of encoding data is provided. The method advantageously includes block encoding the data to generate a plurality of code words; and repeating each code word a predefined number of times.

In one embodiment, the method advantageously includes block encoding the data as a matrix of three rows and thirty-two columns, and repeating each code word four times, wherein the first row of the matrix from left to right is a binary number having a hexadecimal value of 2492DBBF followed by two zeros, the second row of the matrix from left to right is a zero followed by a binary number having a hexadecimal value of 2492DBBF

followed by another zero, and the third row of the matrix from left to right is two zeros followed by a binary number having a hexadecimal value of 2492DBBF.

BRIEF DESCRIPTION OF THE DRAWINGS

The features, objects, and advantages of the present invention will become more apparent from the detailed description set forth below when taken in conjunction with the drawings in which like reference characters identify correspondingly throughout and wherein:

FIG. 1 is a diagram of a data communication system comprising a plurality of cells, a plurality of base stations and a plurality of mobile stations;

FIG. 2 is an exemplary block diagram of the subsystems of the data communication system of FIG. 1;

FIGS. 3A-3B are block diagrams of an exemplary forward link architecture;

FIG. 4A is a diagram of an exemplary forward link frame structure;

FIGS. 4B-4C are diagrams of an exemplary forward traffic channel and power control channel, respectively;

FIG. 4D is a diagram of a punctured packet;

FIGS. 4E-4G are diagrams of two exemplary data packet formats and the control channel capsule, respectively;

FIG. 5 is an exemplary timing diagram showing high rate packet transmission on the forward link;

FIG. 6 is a block diagram of an exemplary reverse link architecture;

FIG. 7A is a diagram of an exemplary reverse link frame structure;

FIG. 7B is a diagram of an exemplary reverse link access channel;

FIG. 8 is an exemplary timing diagram showing high rate data transmission on the reverse link;

FIG. 9 is an exemplary state diagram showing the transitions between the various operating states of a mobile station;

FIG. 10 is a diagram of the cumulative distribution function (CDF) of the C/I distribution in an ideal hexagonal cellular layout; and

FIG. 11 is a block diagram of a reverse rate indicator (RRI) encoder of the reverse link architecture of FIG. 6.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In accordance with an exemplary embodiment of a data communication system, forward link data transmission occurs from one base station to one mobile station (see FIG. 1) at or near the maximum data rate that can be supported by the forward link and the system. Reverse link data communication can occur from one mobile station to one or more base stations. The calculation of the maximum data rate for forward link transmission is described in detail below. Data is partitioned into data packets, with each data packet being transmitted over one or more time slots (or slots). At each time slot, the base station can direct data transmission to any mobile station which is in communication with the base station.

Initially, the mobile station establishes communication with a base station using a predetermined access procedure. In this connected state, the mobile station can receive data and control messages from the base station, and is able to transmit data and control messages to the base station. The mobile station then monitors the forward link for transmissions from the base stations in the active set of the mobile station. The active set contains a list of base stations in communication with the mobile station. Specifically, the mobile station measures the signal-to-noise-and-interference ratio (C/I) of the forward link pilot from the base stations in the active set, as received at the mobile station. If the received pilot signal is above a predetermined add threshold or below a predetermined drop threshold , the mobile station reports this to the base station. Subsequent messages from the base station direct the mobile station to add or delete the base station(s) to or from its active set, respectively. The various operating states of the mobile station are described below.

If there is no data to send, the mobile station returns to an idle state and discontinues transmission of data rate information to the base station(s). While the mobile station is in the idle state, the mobile station monitors the control channel from one or more base stations in the active set for paging messages.

If there is data to be transmitted to the mobile station, the data is sent by a central controller to all base stations in the active set and stored in a queue at each base station. A paging message is then sent by one or more base stations to the mobile station on the respective control channels. The base station may transmit all such paging messages at the same time across several base stations in order to ensure reception even when the mobile station is switching between base stations. The mobile station demodulates and decodes the signals on one or more control channels to receive the paging messages.

Upon decoding the paging messages, and for each time slot until the data transmission is completed, the mobile station measures the C/I of the

forward link signals from the base stations in the active set, as received at the mobile station. ‘ The C/I of the forward link signals can be obtained by measuring the respective pilot signals. The mobile station then selects the best base station based on a set of parameters. The set of parameters can comprise the present and previous C/I measurements and the bit-error-rate or packet-error-rate. For example, the best base station can be selected based on the largest C/I measurement. The mobile station then identifies the best base station and transmits to the selected base station a data request message (hereinafter referred to as the DRC message) on the data request channel (hereinafter referred to as the DRC channel). The DRC message can contain the requested data rate or, alternatively, an indication of the quality of the forward link channel (e.g., the C/I measurement itself, the bit-error-rate, or the packet-error-rate). In an exemplary embodiment, the mobile station can direct the transmission of the DRC message to a specific base station by the use of a Walsh code which uniquely identifies the base station. The DRC message symbols are exclusively OR'ed (XOR) with the unique Walsh code. Since each base station in the active set of the mobile station is identified by a unique Walsh code, only the selected base station which performs the identical XOR operation as that performed by the mobile station, with the correct Walsh code, can correctly decode the DRC message. The base station uses the rate control information from each mobile station to efficiently transmit forward link data at the highest possible rate.

At each time slot, the base station can select any of the paged mobile stations for data transmission. The base station then determines the data rate at which to transmit the data to the selected mobile station based on the most recent value of the DRC message received from the mobile station. Additionally, the base station uniquely identifies a transmission to a particular mobile station by using a spreading code which is unique to that mobile station. In an exemplary embodiment, this spreading code is the long pseudo noise (PN) code which is defined by IS-95 standard.

The mobile station, for which the data packet is intended, receives the data transmission and decodes the data packet. Each data packet comprises a plurality of data units. In an exemplary embodiment, a data unit comprises eight information bits, although different data unit sizes can be defined and are within the scope of the present invention. In an exemplary embodiment, each data unit is associated with a sequence number and the mobile stations are able to identify either missed or duplicative transmissions. In such events, the mobile stations communicate via the reverse link data channel the sequence

numbers of the missing data units. The base station controllers, which receive the data messages from the mobile stations, then indicate to all base stations communicating with this particular mobile station which data units were not received by the mobile station. The base stations then schedule a retransmission of such data units.

Each mobile station in the data communication system can communicate with multiple base stations on the reverse link. In an exemplary embodiment, the data communication system of the present invention supports soft handoff and softer handoff on the reverse link for several reasons. First, soft handoff does not consume additional capacity on the reverse link but rather allows the mobile stations to transmit data at the minimum power level such that at least one of the base stations can reliably decode the data. Second, reception of the reverse link signals by more base stations increases the reliability of the transmission and only requires additional hardware at the base stations.

In an exemplary embodiment, the forward link capacity of a data transmission system is determined by the rate requests of the mobile stations. Additional gains in the forward link capacity can be achieved by using directional antennas and/or adaptive spatial filters. An exemplary method and apparatus for providing directional transmissions are disclosed in copending U.S. Patent No. 5,857,147, entitled "METHOD AND APPARATUS FOR DETERMINING THE TRANSMISSION DATA RATE IN A MULTI-USER COMMUNICATION SYSTEM", issued January 5, 1999, and U.S. Patent Application Serial No. 08/925,521, entitled "METHOD AND APPARATUS FOR PROVIDING ORTHOGONAL SPOT BEAMS, SECTORS, AND PICOCELLS", filed September 8, 1997, both assigned to the assignee of the present invention and incorporated by reference herein.

I. System Description

Referring to the drawings, FIG. 1 represents an exemplary data communication system in accordance with one embodiment that comprises multiple cells **2a** - **2g**. Each cell **2** is serviced by a corresponding base station **4**. Various mobile stations **6** are dispersed throughout the data communication system. In an exemplary embodiment, each of mobile stations **6** communicates with at most one base station **4** on the forward link at each time slot but can be in communication with one or more base stations **4** on the reverse link, depending on whether the mobile station **6** is in soft handoff. For example, base

station **4a** transmits data exclusively to mobile station **6a**, base station **4b** transmits data exclusively to mobile station **6b**, and base station **4c** transmits data exclusively to mobile station **6c** on the forward link at time slot n. In FIG. 1, the solid line with the arrow indicates a data transmission from base station **4** to mobile station **6**. A broken line with the arrow indicates that mobile station **6** is receiving the pilot signal, but no data transmission, from base station **4**. The reverse link communication is not shown in FIG. 1 for simplicity.

As shown by FIG. 1, each base station **4** preferably transmits data to one mobile station **6** at any given moment. Mobile stations **6**, especially those located near a cell boundary, can receive the pilot signals from multiple base stations **4**. If the pilot signal is above a predetermined threshold, mobile station **6** can request that base station **4** be added to the active set of mobile station **6**. In an exemplary embodiment, mobile station **6** can receive data transmission from zero or one member of the active set.

A block diagram illustrating the basic subsystems of the data communication system of FIG. 1 is shown in FIG. 2. Base station controller **10** interfaces with packet network interface **24**, PSTN **30**, and all base stations **4** in the data communication system (only one base station **4** is shown in FIG. 2 for simplicity). Base station controller **10** coordinates the communication between mobile stations **6** in the data communication system and other users connected to packet network interface **24** and PSTN **30**. PSTN **30** interfaces with users through the standard telephone network (not shown in FIG. 2).

Base station controller **10** contains many selector elements **14**, although only one is shown in FIG. 2 for simplicity. One selector element **14** is assigned to control the communication between one or more base stations 4 and one mobile station **6**. If selector element **14** has not been assigned to mobile station **6**, call control processor **16** is informed of the need to page mobile station **6**. Call control processor **16** then directs base station **4** to page mobile station **6**.

Data source **20** contains the data which is to be transmitted to mobile station **6**. Data source **20** provides the data to packet network interface **24**. Packet network interface **24** receives the data and routes the data to selector element **14**. Selector element **14** sends the data to each base station **4** in communication with mobile station **6**. Each base station **4** maintains data queue **40** which contains the data to be transmitted to mobile station **6**.

In an exemplary embodiment, on the forward link, a data packet refers to a predetermined amount of data which is independent of the data rate. The data packet is formatted with other control and coding bits and encoded. If data transmission occurs over multiple Walsh channels, the encoded packet is

demultiplexed into parallel streams, with each stream transmitted over one Walsh channel.

The data is sent, in data packets, from data queue **40** to channel element **42**. For each data packet, channel element **42** inserts the necessary control fields. The data packet, control fields, frame check sequence bits, and code tail bits comprise a formatted packet. Channel element **42** then encodes one or more formatted packets and interleaves (or reorders) the symbols within the encoded packets. Next, the interleaved packet is scrambled with a scrambling sequence, covered with Walsh covers, and spread with the long PN code and the short PN_I and PN_Q codes. The spread data is quadrature modulated, filtered, and amplified by a transmitter within RF unit **44**. The forward link signal is transmitted over the air through antenna **46** on forward link **50**.

At mobile station **6**, the forward link signal is received by antenna **60** and routed to a receiver within front end **62**. The receiver filters, amplifies, quadrature demodulates, and quantizes the signal. The digitized signal is provided to demodulator (DEMOD) **64** where it is despread with the long PN code and the short PN_I and PN_Q codes, decovered with the Walsh covers, and descrambled with the identical scrambling sequence. The demodulated data is provided to decoder **66** which performs the inverse of the signal processing functions done at base station **4**, specifically the de-interleaving, decoding, and frame check functions. The decoded data is provided to data sink **68**. The hardware, as described above, supports transmissions of data, messaging, voice, video, and other communications over the forward link.

The system control and scheduling functions can be accomplished by many implementations. The location of channel scheduler **48** is dependent on whether a centralized or distributed control/scheduling processing is desired. For example, for distributed processing, channel scheduler **48** can be located within each base station **4**. Conversely, for centralized processing, channel scheduler **48** can be located within base station controller **10** and can be designed to coordinate the data transmissions of multiple base stations **4**. Other implementations of the above described functions can be contemplated and are within the scope of the present invention.

As shown in FIG. 1, mobile stations **6** are dispersed throughout the data communication system and can be in communication with zero or one base station **4** on the forward link. In an exemplary embodiment, channel scheduler **48** coordinates the forward link data transmissions of one base station **4**. In an exemplary embodiment, channel scheduler **48** connects to data queue **40** and channel element **42** within base station **4** and receives the queue size, which is

indicative of the amount of data to transmit to mobile station **6**, and the DRC messages from mobile stations **6**. Channel scheduler **48** schedules high rate data transmission such that the system goals of maximum data throughput and minimum transmission delay are optimized.

In an exemplary embodiment, the data transmission is scheduled based in part on the quality of the communication link. An exemplary communication system that selects the transmission rate based on the link quality is disclosed in U.S. Patent Application Serial No. 08/741,320, entitled "METHOD AND APPARATUS FOR PROVIDING HIGH SPEED DATA COMMUNICATIONS IN A CELLULAR ENVIRONMENT", filed September 11, 1996, assigned to the assignee of the present invention and incorporated by reference herein. In the presently disclosed embodiments, the scheduling of the data communication can be based on additional considerations such as the GOS of the user, the queue size, the type of data, the amount of delay already experienced, and the error rate of the data transmission. These considerations are described in detail in U.S. Patent Application No. 08/798,951, entitled "METHOD AND APPARATUS FOR FORWARD LINK RATE SCHEDULING", filed February 11, 1997, and U.S. Patent Application Serial No. 08/914,928, entitled "METHOD AND APPARATUS FOR REVERSE LINK RATE SCHEDULING", filed August 20, 1997, both are assigned to the assignee of the present invention and incorporated by reference herein. Other factors can be considered in scheduling data transmissions and are within the scope of the present invention.

The data communication system of the presently disclosed embodiments advantageously supports data and message transmissions on the reverse link. Within mobile station **6**, controller **76** processes the data or message transmission by routing the data or message from data source **70** to encoder **72**. Controller **76** can be implemented in a microcontroller, a microprocessor, a digital signal processing (DSP) chip, or an ASIC programmed to perform the function as described herein.

In an exemplary embodiment, encoder **72** encodes the message consistent with the Blank and Burst signaling data format described in the aforementioned U.S. Patent No. 5,504,773. Encoder **72** then generates and appends a set of CRC bits, appends a set of code tail bits, encodes the data and appended bits, and reorders the symbols within the encoded data. The interleaved data is provided to modulator (MOD) **74**.

Modulator **74** can be implemented in many embodiments. In an exemplary embodiment (see FIG. 6), the interleaved data is covered with Walsh

codes, spread with a long PN code, and further spread with the short PN codes. The spread data is provided to a transmitter within front end **62**. The transmitter modulates, filters, amplifies, and transmits the reverse link signal over the air, through antenna **60**, on reverse link **52**.

In an exemplary embodiment, mobile station **6** spreads the reverse link data in accordance with a long PN code. Each reverse link channel is defined in accordance with the temporal offset of a common long PN sequence. At two differing offsets the resulting modulation sequences are uncorrelated. The offset of a mobile station **6** is determined in accordance with a unique numerical identification of mobile station **6**, which In an exemplary embodiment of the IS-95 mobile stations **6** is the mobile station specific identification number. Thus, each mobile station **6** transmits on one uncorrelated reverse link channel determined in accordance with its unique electronic serial number.

At base station **4**, the reverse link signal is received by antenna **46** and provided to RF unit **44**. RF unit **44** filters, amplifies, demodulates, and quantizes the signal and provides the digitized signal to channel element **42**. Channel element **42** despreads the digitized signal with the short PN codes and the long PN code. Channel element **42** also performs the Walsh code decovering and pilot and DRC extraction. Channel element **42** then reorders the demodulated data, decodes the de-interleaved data, and performs the CRC check function. The decoded data, e.g. the data or message, is provided to selector element **14**. Selector element **14** routes the data and message to the appropriate destination. Channel element **42** may also forward a quality indicator to selector element **14** indicative of the condition of the received data packet.

In an exemplary embodiment, mobile station **6** can be in one of three operating states. An exemplary state diagram showing the transitions between the various operating states of mobile station **6** is shown in FIG. 9. In the access state **902**, mobile station **6** sends access probes and waits for channel assignment by base station **4**. The channel assignment comprises allocation of resources, such as a power control channel and frequency allocation. Mobile station **6** can transition from the access state **902** to the connected state **904** if mobile station **6** is paged and alerted to an upcoming data transmission, or if mobile station **6** transmits data on the reverse link. In the connected state **904**, mobile station **6** exchanges (e.g., transmits or receives) data and performs handoff operations. Upon completion of a release procedure, mobile station **6** transitions from the connected state **904** to the idle state **906**. Mobile station **6** can also transition from the access state **902** to the idle state **906** upon being rejected for a

connection with base station **4**. In the idle state **906**, mobile station **6** listens to overhead and paging messages by receiving and decoding messages on the forward control channel and performs idle handoff procedure. Mobile station **6** can transition to the access state **902** by initiating access procedure. The state diagram shown in FIG. 9 is only an exemplary state definition which is shown for illustration. Other state diagrams can also be utilized and are within the scope of the present invention.

II. Forward Link Data Transmission

In an exemplary embodiment, the initiation of a communication between mobile station **6** and base station **4** occurs in a similar manner as that for the CDMA system. After completion of the call set up, mobile station **6** monitors the control channel for paging messages. While in the connected state, mobile station **6** begins transmission of the pilot signal on the reverse link.

An exemplary flow diagram of forward link high rate data transmission is shown in FIG. 5. If base station **4** has data to transmit to mobile station **6**, base station **4** sends a paging message addressed to mobile station **6** on the control channel at block **502**. The paging message can be sent from one or multiple base stations **4**, depending on the handoff state of mobile station **6**. Upon reception of the paging message, mobile station **6** begins the C/I measurement process at block **504**. The C/I of the forward link signal is calculated from one or a combination of methods described below. Mobile station **6** then selects a requested data rate based on the best C/I measurement and transmits a DRC message on the DRC channel at block **506**.

Within the same time slot, base station **4** receives the DRC message at block **508**. If the next time slot is available for data transmission, base station **4** transmits data to mobile station **6** at the requested data rate at block **510**. Mobile station **6** receives the data transmission at block **512**. If the next time slot is available, base station **4** transmits the remainder of the packet at block **514** and mobile station **6** receives the data transmission at block **516**.

In one embodiment mobile station **6** can be in communication with one or more base stations **4** simultaneously. The actions taken by mobile station **6** depend on whether mobile station **6** is or is not in soft handoff. These two cases are discussed separately below.

III. No Handoff Case

In the no handoff case, mobile station **6** communicates with one base station **4**. Referring to FIG. 2, the data destined for a particular mobile station **6** is provided to selector element **14** which has been assigned to control the communication with that mobile station **6**. Selector element **14** forwards the data to data queue **40** within base station **4**. Base station **4** queues the data and transmits a paging message on the control channel. Base station **4** then monitors the reverse link DRC channel for DRC messages from mobile station **6**. If no signal is detected on the DRC channel, base station **4** can retransmit the paging message until the DRC message is detected. After a predetermined number of retransmission attempts, base station **4** can terminate the process or re-initiate a call with mobile station **6**.

In an exemplary embodiment, mobile station **6** transmits the requested data rate, in the form of a DRC message, to base station **4** on the DRC channel. In the alternative embodiment, mobile station **6** transmits an indication of the quality of the forward link channel (e.g., the C/I measurement) to base station **4**. In an exemplary embodiment, the 3-bit DRC message is decoded with soft decisions by base station **4**. In an exemplary embodiment, the DRC message is transmitted within the first half of each time slot. Base station **4** then has the remaining half of the time slot to decode the DRC message and configure the hardware for data transmission at the next successive time slot, if that time slot is available for data transmission to this mobile station **6**. If the next successive time slot is not available, base station **4** waits for the next available time slot and continues to monitor the DRC channel for the new DRC messages.

In the first embodiment, base station **4** transmits at the requested data rate. This embodiment confers to mobile station **6** the important decision of selecting the data rate. Always transmitting at the requested data rate has the advantage that mobile station **6** knows which data rate to expect. Thus, mobile station **6** only demodulates and decodes the traffic channel in accordance with the requested data rate. Base station **4** does not have to transmit a message to mobile station **6** indicating which data rate are being used by base station **4**.

In the first embodiment, after reception of the paging message, mobile station **6** continuously attempts to demodulate the data at the requested data rate. Mobile station **6** demodulates the forward traffic channel and provides the soft decision symbols to the decoder. The decoder decodes the symbols and performs the frame check on the decoded packet to determine whether the packet was received correctly. If the packet was received in error or if the

packet was directed for another mobile station **6**, the frame check would indicate a packet error. Alternatively in the first embodiment, mobile station **6** demodulates the data on a slot by slot basis. In an exemplary embodiment, mobile station **6** is able to determine whether a data transmission is directed for it based on a preamble which is incorporated within each transmitted data packet, as described below. Thus, mobile station **6** can terminate the decoding process if it is determined that the transmission is directed for another mobile station **6**. In either case, mobile station **6** transmits a negative acknowledgments (NACK) message to base station **4** to acknowledge the incorrect reception of the data units. Upon receipt of the NACK message, the data units received in error is retransmitted.

The transmission of the NACK messages can be implemented in a manner similar to the transmission of the error indicator bit (EIB) in the CDMA system. The implementation and use of EIB transmission are disclosed in U.S. Patent No. 5,568,483, entitled "METHOD AND APPARATUS FOR THE FORMATTING OF DATA FOR TRANSMISSION", assigned to the assignee of the present invention and incorporated by reference herein. Alternatively, NACK can be transmitted with messages.

In the second embodiment, the data rate is determined by base station **4** with input from mobile station **6**. Mobile station **6** performs the C/I measurement and transmits an indication of the link quality (e.g., the C/I measurement) to base station **4**. Base station **4** can adjust the requested data rate based on the resources available to base station **4**, such as the queue size and the available transmit power. The adjusted data rate can be transmitted to mobile station **6** prior to or concurrent with data transmission at the adjusted data rate, or can be implied in the encoding of the data packets. In the first case, wherein mobile station **6** receives the adjusted data rate before the data transmission, mobile station **6** demodulates and decodes the received packet in the manner described in the first embodiment. In the second case, wherein the adjusted data rate is transmitted to mobile station **6** concurrent with the data transmission, mobile station **6** can demodulate the forward traffic channel and store the demodulated data. Upon receipt of the adjusted data rate, mobile station **6** decodes the data in accordance with the adjusted data rate. And in the third case, wherein the adjusted data rate is implied in the encoded data packets, mobile station **6** demodulates and decodes all candidate rates and determine a posteriori the transmit rate for selection of the decoded data. A method and apparatus for performing rate determination are described in detail in U.S. Patent No. 5,751,725, entitled "METHOD AND APPARATUS FOR

DETERMINING THE RATE OF RECEIVED DATA IN A VARIABLE RATE COMMUNICATION SYSTEM", issued May 12, 1998, and Patent Application Serial No. 08/908,866, also entitled "METHOD AND APPARATUS FOR DETERMINING THE RATE OF RECEIVED DATA IN A VARIABLE RATE COMMUNICATION SYSTEM", filed August 8, 1997, both assigned to the assignee of the present invention and incorporated by reference herein. For all cases described above, mobile station **6** transmits a NACK message as described above if the outcome of the frame check is negative.

The discussion hereinafter is based on the first embodiment wherein mobile station **6** transmits to base station **4** the DRC message indicative of the requested data rate, except as otherwise indicated. However, the inventive concept described herein is equally applicable to the second embodiment wherein mobile station **6** transmits an indication of the link quality to base station **4**.

IV. Handoff Case

In the handoff case, mobile station **6** communicates with multiple base stations **4** on the reverse link. In an exemplary embodiment, data transmission on the forward link to a particular mobile station **6** occurs from one base station **4**. However, mobile station **6** can simultaneously receive the pilot signals from multiple base stations **4**. If the C/I measurement of a base station **4** is above a predetermined threshold, the base station **4** is added to the active set of mobile station **6**. During the soft handoff direction message, the new base station **4** assigns mobile station **6** to a reverse power control (RPC) Walsh channel of which is described below. Each base station **4** in soft handoff with mobile station **6** monitors the reverse link transmission and sends an RPC bit on their respective RPC Walsh channels.

Referring to FIG. 2, selector element **14** assigned to control the communication with mobile station **6** forwards the data to all base stations **4** in the active set of mobile station **6**. All base stations **4** that receive data from selector element **14** transmit a paging message to mobile station **6** on their respective control channels. When mobile station **6** is in the connected state, mobile station **6** performs two functions. First, mobile station **6** selects the best base station **4** based on a set of parameters that can be the best C/I measurement. Mobile station **6** then selects a data rate corresponding to the C/I measurement and transmits a DRC message to the selected base station **4**.

Mobile station **6** can direct transmission of the DRC message to a particular base station **4** by covering the DRC message with the Walsh cover assigned to that particular base station **4**. Second, mobile station **6** attempts to demodulate the forward link signal in accordance with the requested data rate at each subsequent time slot.

After transmitting the paging messages, all base stations **4** in the active set monitor the DRC channel for a DRC message from mobile station **6**. Again, because the DRC message is covered with a Walsh code, the selected base station **4** assigned with the identical Walsh cover is able to decover the DRC message. Upon receipt of the DRC message, the selected base station **4** transmits data to mobile station **6** at the next available time slots.

In an exemplary embodiment, base station **4** transmits data in packets comprising a plurality of data units at the requested data rate to mobile station **6**. If the data units are incorrectly received by mobile station **6**, a NACK message is transmitted on the reverse links to all base stations **4** in the active set. In an exemplary embodiment, the NACK message is demodulated and decoded by base stations **4** and forwarded to selector element **14** for processing. Upon processing of the NACK message, the data units are retransmitted using the procedure as described above. In an exemplary embodiment, selector element **14** combines the NACK signals received from all base stations **4** into one NACK message and sends the NACK message to all base stations **4** in the active set.

In an exemplary embodiment, mobile station **6** can detect changes in the best C/I measurement and dynamically request data transmissions from different base stations **4** at each time slot to improve efficiency. In an exemplary embodiment, since data transmission occurs from only one base station **4** at any given time slot, other base stations **4** in the active set may not be aware which data units, if any, have been transmitted to mobile station **6**. In an exemplary embodiment, the transmitting base station **4** informs selector element **14** of the data transmission. Selector element **14** then sends a message to all base stations **4** in the active set. In an exemplary embodiment, the transmitted data is presumed to have been correctly received by mobile station **6**. Therefore, if mobile station **6** requests data transmission from a different base station **4** in the active set, the new base station **4** transmits the remaining data units. In an exemplary embodiment, the new base station **4** transmits in accordance with the last transmission update from selector element **14**. Alternatively, the new base station **4** selects the next data units to transmit using predictive schemes based on metrics such as the average transmission rate and prior updates from selector element **14**. These mechanisms minimize duplicative retransmissions

of the same data units by multiple base stations **4** at different time slots which results in a loss in efficiency. If a prior transmission was received in error, base stations **4** can retransmit those data units out of sequence since each data unit is identified by a unique sequence number as described below. In an exemplary embodiment, if a hole (or non-transmitted data units) is created (e.g., as the result of handoff between one base station **4** to another base station **4**), the missing data units are considered as though received in error. Mobile station **6** transmits NACK messages corresponding to the missing data units and these data units are retransmitted.

In an exemplary embodiment, each base station **4** in the active set maintains an independent data queue **40** which contains the data to be transmitted to mobile station **6**. The selected base station **4** transmits data existing in its data queue **40** in a sequential order, except for retransmissions of data units received in error and signaling messages. In an exemplary embodiment, the transmitted data units are deleted from queue **40** after transmission.

V. Other Considerations for Forward Link Data Transmissions

An important consideration in the data communication system of the presently disclosed embodiments is the accuracy of the C/I estimates for the purpose of selecting the data rate for future transmissions. In an exemplary embodiment, the C/I measurements are performed on the pilot signals during the time interval when base stations **4** transmit pilot signals. In an exemplary embodiment, since only the pilot signals are transmitted during this pilot time interval, the effects of multipath and interference are minimal.

In other implementations wherein the pilot signals are transmitted continuously over an orthogonal code channel, similar to that for the IS-95 systems, the effect of multipath and interference can distort the C/I measurements. Similarly, when performing the C/I measurement on the data transmissions instead of the pilot signals, multipath and interference can also degrade the C/I measurements. In both of these cases, when one base station **4** is transmitting to one mobile station **6**, the mobile station **6** is able to accurately measure the C/I of the forward link signal because no other interfering signals are present. However, when mobile station **6** is in soft handoff and receives the pilot signals from multiple base stations **4**, mobile station **6** is not able to discern whether or not base stations **4** were transmitting data. In the worst case

scenario, mobile station **6** can measure a high C/I at a first time slot, when no base stations **4** were transmitting data to any mobile station **6**, and receive data transmission at a second time slot, when all base stations 4 are transmitting data at the same time slot. The C/I measurement at the first time slot, when all base stations **4** are idle, gives a false indication of the forward link signal quality at the second time slot since the status of the data communication system has changed. In fact, the actual C/I at the second time slot can be degraded to the point that reliable decoding at the requested data rate is not possible.

The converse extreme scenario exists when a C/I estimate by mobile station **6** is based on maximal interference. However, the actual transmission occurs when only the selected base station is transmitting, In this case, the C/I estimate and selected data rate are conservative and the transmission occurs at a rate lower than that which could be reliably decoded, thus reducing the transmission efficiency.

In the implementation wherein the C/I measurement is performed on a continuous pilot signal or the traffic signal, the prediction of the C/I at the second time slot based on the measurement of the C/I at the first time slot can be made more accurate by three embodiments. In the first embodiment, data transmissions from base stations **4** are controlled so that base stations **4** do not constantly toggle between the transmit and idle states at successive time slots. This can be achieved by queuing enough data (e.g. a predetermined number of information bits) before actual data transmission to mobile stations **6**.

In the second embodiment, each base station **4** transmits a forward activity bit (hereinafter referred to as the FAC bit) which indicates whether a transmission will occur at the next half frame. The use of the FAC bit is described in detail below. Mobile station **6** performs the C/I measurement taking into account the received FAC bit from each base station **4**.

In the third embodiment, which corresponds to the scheme wherein an indication of the link quality is transmitted to base station **4** and which uses a centralized scheduling scheme, the scheduling information indicating which ones of base stations **4** transmitted data at each time slot is made available to channel scheduler **48**. Channel scheduler **48** receives the C/I measurements from mobile stations **6** and can adjust the C/I measurements based on its knowledge of the presence or absence of data transmission from each base station **4** in the data communication system. For example, mobile station **6** can measure the C/I at the first time slot when no adjacent base stations **4** are transmitting. The measured C/I is provided to channel scheduler **48**. Channel scheduler **48** knows that no adjacent base stations **4** transmitted data in the first

time slot since none was scheduled by channel scheduler **48**. In scheduling data transmission at the second time slot, channel scheduler **48** knows whether one or more adjacent base stations **4** will transmit data. Channel scheduler **48** can adjust the C/I measured at the first time slot to take into account the additional interference mobile station **6** will receive in the second time slot due to data transmissions by adjacent base stations **4**. Alternately, if the C/I is measured at the first time slot when adjacent base stations **4** are transmitting and these adjacent base stations **4** are not transmitting at the second time slot, channel scheduler **48** can adjust the C/I measurement to take into account the additional information.

Another important consideration is to minimize redundant retransmissions. Redundant retransmissions can result from allowing mobile station **6** to select data transmission from different base stations **4** at successive time slots. The best C/I measurement can toggle between two or more base stations **4** over successive time slots if mobile station **6** measures approximately equal C/I for these base stations **4**. The toggling can be due to deviations in the C/I measurements and/or changes in the channel condition. Data transmission by different base stations **4** at successive time slots can result in a loss in efficiency.

The toggling problem can be addressed by the use of hysteresis. The hysteresis can be implemented with a signal level scheme, a timing scheme, or a combination of the signal level and timing schemes. In the exemplary signal level scheme, the better C/I measurement of a different base station **4** in the active set is not selected unless it exceeds the C/I measurement of the current transmitting base station **4** by at least the hysteresis quantity. As an example, assume that the hysteresis is 1.0 dB and that the C/I measurement of the first base station **4** is 3.5 dB and the C/I measurement of the second base station **4** is 3.0 dB at the first time slot. At the next time slot, the second base station **4** is not selected unless its C/I measurement is at least 1.0 dB higher than that of the first base station **4**. Thus, if the C/I measurement of the first base station **4** is still 3.5 dB at the next time slot, the second base station **4** is not selected unless its C/I measurement is at least 4.5 dB.

In an exemplary timing scheme, base station **4** transmits data packets to mobile station **6** for a predetermined number of time slots. Mobile station **6** is not allowed to select a different transmitting base station **4** within the predetermined number of time slots. Mobile station **6** continues to measure the C/I of the current transmitting base station **4** at each time slot and selects the data rate in response to the C/I measurement.

Yet another important consideration is the efficiency of the data transmission. Referring to FIGS. 4E and 4F, each data packet format **410** and **430** contains data and overhead bits. In an exemplary embodiment, the number of overhead bits is fixed for all data rates. At the highest data rate, the percentage of overhead is small relative to the packet size and the efficiency is high. At the lower data rates, the overhead bits can comprise a larger percentage of the packet. The inefficiency at the lower data rates can be improved by transmitting variable length data packets to mobile station **6**. The variable length data packets can be partitioned and transmitted to mobile station **6** over multiple time slots. Advantageously, the variable length data packets are transmitted to mobile station **6** over successive time slots to simplify the processing. The presently disclosed embodiments are directed to the use of various packet sizes for various supported data rates to improve the overall transmission efficiency.

VI. Forward Link Architecture

In an exemplary embodiment, base station **4** transmits at the maximum power available to base station **4** and at the maximum data rate supported by the data communication system to a single mobile station **6** at any given slot. The maximum data rate that can be supported is dynamic and depends on the C/I of the forward link signal as measured by mobile station **6**. Advantageously, base station **4** transmits to only one mobile station **6** at any given time slot.

To facilitate data transmission, the forward link comprises four time multiplexed channels : the pilot channel, power control channel, control channel, and traffic channel. The function and implementation of each of these channels are described below. In an exemplary embodiment, the traffic and power control channels each comprises a number of orthogonally spread Walsh channels. In one embodiment the traffic channel is used to transmit traffic data and paging messages to mobile stations **6**. When used to transmit paging messages, the traffic channel is also referred to as the control channel in this specification.

In an exemplary embodiment, the bandwidth of the forward link is selected to be 1.2288 MHz. This bandwidth selection allows the use of existing hardware components designed for a CDMA system that conforms to the IS-95 standard. However, the data communication system of the present invention

can be adopted for use with different bandwidths to improve capacity and/or to conform to system requirements. For example, a 5 MHz bandwidth can be utilized to increase the capacity. Furthermore, the bandwidths of the forward link and the reverse link can be different (e.g., 5 MHz bandwidth on the forward link and 1.2288 MHz bandwidth on the reverse link) to more closely match link capacity with demand.

In an exemplary embodiment, the short PN_I and PN_Q codes are the same length 2^{15} PN codes that are specified by the IS-95 standard. At the 1.2288 MHz chip rate, the short PN sequences repeat every 26.67 msec {26.67 msec = $2^{15}/1.2288\text{x}10^6$}. In an exemplary embodiment, the same short PN codes are used by all base stations **4** within the data communication system. However, each base station **4** is identified by a unique offset of the basic short PN sequences. In an exemplary embodiment, the offset is in increments of 64 chips. Other bandwidth and PN codes can be utilized and are within the scope of the present invention.

VII. Forward Link Traffic Channel

A block diagram of an exemplary forward link architecture is shown in FIG. 3A. The data is partitioned into data packets and provided to CRC encoder **112**. For each data packet, CRC encoder **112** generates frame check bits (e.g., the CRC parity bits) and inserts the code tail bits. The formatted packet from CRC encoder **112** comprises the data, the frame check and code tail bits, and other overhead bits that are described below. The formatted packet is provided to encoder **114**, which in an exemplary embodiment, encodes the packet in accordance with the encoding format disclosed in the aforementioned U.S. Patent No. 5,933,462. Other encoding formats can also be used and are within the scope of the present invention. The encoded packet from encoder **114** is provided to interleaver **116** which reorders the code symbols in the packet. The interleaved packet is provided to frame puncture element **118** which removes a fraction of the packet in the manner described below. The punctured packet is provided to multiplier **120** which scrambles the data with the scrambling sequence from scrambler **122**. Puncture element **118** and scrambler **122** are described in detail below. The output from multiplier **120** comprises the scrambled packet.

The scrambled packet is provided to variable rate controller **130** which demultiplexes the packet into K parallel inphase and quadrature channels,

where K is dependent on the data rate. In an exemplary embodiment, the scrambled packet is first demultiplexed into the inphase (I) and quadrature (Q) streams. In an exemplary embodiment, the I stream comprises even indexed symbols and the Q stream comprises odd indexed symbol. Each stream is further demultiplexed into K parallel channels such that the symbol rate of each channel is fixed for all data rates. The K channels of each stream are provided to Walsh cover element **132** which covers each channel with a Walsh function to provide orthogonal channels. The orthogonal channel data are provided to gain element **134** which scales the data to maintain a constant total-energy-per-chip (and hence constant output power) for all data rates. The scaled data from gain element **134** is provided to multiplexer (MUX) **160** which multiplexes the data with the preamble. The preamble is discussed in detail below. The output from MUX **160** is provided to multiplexer (MUX) **162** which multiplexes the traffic data, the power control bits, and the pilot data. The output of MUX **162** comprises the I Walsh channels and the Q Walsh channels.

A block diagram of an exemplary modulator used to modulate the data is illustrated in FIG. 3B. The I Walsh channels and Q Walsh channels are provided to summers **212a** and **212b**, respectively, which sum the K Walsh channels to provide the signals I_{sum} and Q_{sum}, respectively. The I_{sum} and Q_{sum} signals are provided to complex multiplier **214**. Complex multiplier **214** also receives the PN_I and PN_Q signals from multipliers **236a** and **236b**, respectively, and multiplies the two complex inputs in accordance with the following equation:

$$\begin{aligned}(I_{mult} + jQ_{mult}) &= (I_{sum} + jQ_{sum}) \bullet (PN\_I + jPN\_Q) \\ &= (I_{sum} \bullet PN\_I - Q_{sum} \bullet PN\_Q) + j(I_{sum} \bullet PN\_Q + Q_{sum} \bullet PN\_I)\end{aligned} \quad , \tag{2}$$

where I_{mult} and Q_{mult} are the outputs from complex multiplier **214** and j is the complex representation. The I_{mult} and Q_{mult} signals are provided to filters **216a** and **216b**, respectively, which filters the signals. The filtered signals from filters **216a** and **216b** are provided to multipliers **218a** and **218b**, respectively, which multiplies the signals with the inphase sinusoid $COS(w_c t)$ and the quadrature sinusoid $SIN(w_c t)$, respectively. The I modulated and Q modulated signals are provided to summer **220** which sums the signals to provide the forward modulated waveform S(t).

In an exemplary embodiment, the data packet is spread with the long PN code and the short PN codes. The long PN code scrambles the packet such that

only the mobile station **6** for which the packet is destined is able to descramble the packet. In an exemplary embodiment, the pilot and power control bits and the control channel packet are spread with the short PN codes but not the long PN code to allow all mobile stations **6** to receive these bits. The long PN sequence is generated by long code generator **232** and provided to multiplexer (MUX) **234**. The long PN mask determines the offset of the long PN sequence and is uniquely assigned to the destination mobile station **6**. The output from MUX **234** is the long PN sequence during the data portion of the transmission and zero otherwise (e.g. during the pilot and power control portion). The gated long PN sequence from MUX **234** and the short PN_I and PN_Q sequences from short code generator **238** are provided to multipliers **236a** and **236b**, respectively, which multiply the two sets of sequences to form the PN_I and PN_Q signals, respectively. The PN_I and PN_Q signals are provided to complex multiplier **214**.

A block diagram of an exemplary traffic channel shown in FIGS. 3A and 3B is one of numerous architectures which support data encoding and modulation on the forward link. Other architectures, such as the architecture for the forward link traffic channel in the CDMA system which conforms to the IS-95 standard, can also be utilized and are within the scope of the present invention.

In an exemplary embodiment, the data rates supported by base stations **4** are predetermined and each supported data rate is assigned a unique rate index. Mobile station **6** selects one of the supported data rates based on the C/I measurement. Since the requested data rate needs to be sent to a base station **4** to direct that base station **4** to transmit data at the requested data rate, a trade off is made between the number of supported data rates and the number of bits needed to identify the requested data rate. In an exemplary embodiment, the number of supported data rates is seven and a 3-bit rate index is used to identify the requested data rate. An exemplary definition of the supported data rates is illustrated in Table 1. Different definition of the supported data rates can be contemplated and are within the scope of the present invention.

In an exemplary embodiment, the minimum data rate is 38.4 Kbps and the maximum data rate is 2.4576 Mbps. The minimum data rate is selected based on the worst case C/I measurement in the system, the processing gain of the system, the design of the error correcting codes, and the desired level of performance. In an exemplary embodiment, the supported data rates are chosen such that the difference between successive supported data rates is 3 dB. The 3 dB increment is a compromise among several factors which include the

accuracy of the C/I measurement that can be achieved by mobile station **6**, the losses (or inefficiencies) which results from the quantization of the data rates based on the C/I measurement, and the number of bits (or the bit rate) needed to transmit the requested data rate from mobile station **6** to base station **4**. More supported data rates requires more bits to identify the requested data rate but allows for more efficient use of the forward link because of smaller quantization error between the calculated maximum data rate and the supported data rate. The present invention is directed to the use of any number of supported data rates and other data rates than those listed in Table 1.

Table 1 - Traffic Channel Parameters

Parameter	Data Rates							Units
	38.4	76.8	153.6	307.2	614.4	1228.8	2457.6	Kbps
Data bit/packet	1024	1024	1024	1024	1024	2048	2048	bits
Packet length	26.67	13.33	6.67	3.33	1.67	1.67	0.83	msec
Slots/packet	16	8	4	2	1	1	0.5	slots
Packet/transmission	1	1	1	1	1	1	2	packets
Slots/transmission	16	8	4	2	1	1	1	slots
Walsh symbol rate	153.6	307.2	614.4	1228.8	2457.6	2457.6	4915.2	Ksps
Walsh channel/ QPSK phase	1	2	4	8	16	16	16	channels
Modulator rate	76.8	76.8	76.8	76.8	76.8	76.8	76.8[1]	ksps
PN chips/data bit	32	16	8	4	2	1	0.5	chips/bit
PN chip rate	1228.8	1228.8	1228.8	1228.8	1228.8	1228.8	1228.8	Kcps
Modulation format	QPSK	QPSK	QPSK	QPSK	QPSK	QPSK	QAM[1]	
Rate index	0	1	2	3	4	5	6	

Note : (1) 16-QAM modulation

A diagram of an exemplary forward link frame structure of the present invention is illustrated in FIG. 4A. The traffic channel transmission is partitioned into frames which, in an exemplary embodiment, are defined as the length of the short PN sequences or 26.67 msec. Each frame can carry control channel information addressed to all mobile stations **6** (control channel frame), traffic data addressed to a particular mobile station **6** (traffic frame), or can be empty (idle frame). The content of each frame is determined by the scheduling performed by the transmitting base station **4**. In an exemplary embodiment, each frame comprises 16 time slots, with each time slot having a duration of 1.667 msec. A time slot of 1.667 msec is adequate to enable mobile station **6** to perform the C/I measurement of the forward link signal. A time slot of 1.667 msec also represents a sufficient amount of time for efficient packet data transmission. In an exemplary embodiment, each time slot is further partitioned into four quarter slots.

In one embodiment each data packet is transmitted over one or more time slots as shown in Table 1. In an exemplary embodiment, each forward link data packet comprises 1024 or 2048 bits. Thus, the number of time slots

required to transmit each data packet is dependent on the data rate and ranges from 16 time slots for the 38.4 Kbps rate to 1 time slot for the 1.2288 Mbps rate and higher.

An diagram of an exemplary forward link slot structure is shown in FIG. 4B. In an exemplary embodiment, each slot comprises three of the four time multiplexed channels, the traffic channel, the control channel, the pilot channel, and the power control channel. In an exemplary embodiment, the pilot and power control channels are transmitted in two pilot and power control bursts which are located at the same positions in each time slot. The pilot and power control bursts are described in detail below.

In an exemplary embodiment, the interleaved packet from interleaver **116** is punctured to accommodate the pilot and power control bursts. In an exemplary embodiment, each interleaved packet comprises 4096 code symbols and the first 512 code symbols are punctured, as shown in FIG. 4D. The remaining code symbols are skewed in time to align to the traffic channel transmission intervals.

The punctured code symbols are scrambled to randomize the data prior to applying the orthogonal Walsh cover. The randomization limits the peak-to-average envelope on the modulated waveform S(t). The scrambling sequence can be generated with a linear feedback shift register, in a manner known in the art. In an exemplary embodiment, scrambler **122** is loaded with the LC state at the start of each slot. In an exemplary embodiment, the clock of scrambler **122** is synchronous with the clock of interleaver **116** but is stalled during the pilot and power control bursts.

In an exemplary embodiment, the forward Walsh channels (for the traffic channel and power control channel) are orthogonally spread with 16-bit Walsh covers at the fixed chip rate of 1.2288 Mcps. The number of parallel orthogonal channels K per inphase and quadrature signal is a function of the data rate, as shown in Table 1. In an exemplary embodiment, for lower data rates, the inphase and quadrature Walsh covers are chosen to be orthogonal sets to minimize cross-talk to the demodulator phase estimate errors. For example, for 16 Walsh channels, an exemplary Walsh assignment is W_0 through W_7 for the inphase signal and W_8 through W_{15} for the quadrature signal.

In an exemplary embodiment, QPSK modulation is used for data rates of 1.2288 Mbps and lower. For QPSK modulation, each Walsh channel comprises one bit. In an exemplary embodiment, at the highest data rate of 2.4576 Mbps, 16-QAM is used and the scrambled data is demultiplexed into 32 parallel streams which are each 2-bit wide, 16 parallel streams for the inphase signal

and 16 parallel streams for the quadrature signal. In an exemplary embodiment, the LSB of each 2-bit symbol is the earlier symbol output from interleaver **116**. In an exemplary embodiment, the QAM modulation inputs of (0, 1, 3, 2) map to modulation values of (+3, +1, -1, -3), respectively. The use of other modulation schemes, such as m-ary phase shift keying PSK, can be contemplated and are within the scope of the present invention.

The inphase and quadrature Walsh channels are scaled prior to modulation to maintain a constant total transmit power which is independent of the data rate. The gain settings are normalized to a unity reference equivalent to unmodulated BPSK. The normalized channel gains G as a function of the number of Walsh channels (or data rate) are shown in Table 2. Also listed in Table 2 is the average power per Walsh channel (inphase or quadrature) such that the total normalized power is equal to unity. Note that the channel gain for 16-QAM accounts for the fact that the normalized energy per Walsh chip is 1 for QPSK and 5 for 16-QAM.

Table 2 - Traffic Channel Orthogonal Channel Gains

	Puncture Duration			
Data Rate (Kbps)	Number of Walsh Channels K	Modulation	Walsh Channel Gain G	Average Power per Channel P_k
38.4	1	QPSK	$1/\sqrt{2}$	½
76.8	2	QPSK	1/2	¼
153.6	4	QPSK	$1/2\sqrt{2}$	1/8
307.2	8	QPSK	1/4	1/16
614.4	16	QPSK	$1/4\sqrt{2}$	1/32
1228.8	16	QPSK	$1/4\sqrt{2}$	1/32
2457.6	16	16-QAM	$1/4\sqrt{10}$	1/32

In one embodiment a preamble is punctured into each traffic frame to assist mobile station **6** in the synchronization with the first slot of each variable rate transmission. In an exemplary embodiment, the preamble is an all-zero sequence which, for a traffic frame, is spread with the long PN code but, for a control channel frame, is not spread with the long PN code. In an exemplary embodiment, the preamble is unmodulated BPSK which is orthogonally spread with Walsh cover W_1. The use of a single orthogonal channel minimizes the peak-to-average envelope. Also, the use of a non-zero Walsh cover W_1

minimizes false pilot detection since, for traffic frames, the pilot is spread with Walsh cover W_0 and both the pilot and the preamble are not spread with the long PN code.

The preamble is multiplexed into the traffic channel stream at the start of the packet for a duration which is a function of the data rate. The length of the preamble is such that the preamble overhead is approximately constant for all data rates while minimizing the probability of false detection. A summary of the preamble as a function of data rates is shown in Table 3. Note that the preamble comprises 3.1 percent or less of a data packet.

Table 3 - Preamble Parameters

	Preamble Puncture Duration		
Data Rate (Kbps)	Walsh Symbols	PN chips	Overhead
38.4	32	512	1.6%
76.8	16	256	1.6%
153.6	8	128	1.6%
307.2	4	64	1.6%
614.4	3	48	2.3%
1228.8	4	64	3.1%
2457.6	2	32	3.1%

VIII. Forward Link Traffic Frame Format

In an exemplary embodiment, each data packet is formatted by the additions of frame check bits, code tail bits, and other control fields. In this specification, an octet is defined as 8 information bits and a data unit is a single octet and comprises 8 information bits.

In an exemplary embodiment, the forward link supports two data packet formats which are illustrated in FIGS. 4E and 4F. Packet format **410** comprises five fields and packet format **430** comprises nine fields. Packet format **410** is used when the data packet to be transmitted to mobile station **6** contains enough data to completely fill all available octets in DATA field **418.** If the amount of data to be transmitted is less than the available octets in DATA field **418**, packet format **430** is used. The unused octets are padded with all zeros and designated as PADDING field **446.**

In an exemplary embodiment, frame check sequence (FCS) fields **412** and **432** contain the CRC parity bits which are generated by CRC generator **112** (see FIG. 3A) in accordance with a predetermined generator polynomial. In an exemplary embodiment, the CRC polynomial is $g(x) = x^{16} + x^{12} + x^5 + 1$, although other polynomials can be used and are within the scope of the present invention. In an exemplary embodiment, the CRC bits are calculated over the FMT, SEQ, LEN, DATA, and PADDING fields. This provides error detection over all bits, except the code tail bits in TAIL fields **420** and **448**, transmitted over the traffic channel on the forward link. In the alternative embodiment, the CRC bits are calculated only over the DATA field. In an exemplary embodiment, FCS fields **412** and **432** contain 16 CRC parity bits, although other CRC generators providing different number of parity bits can be used and are within the scope of the present invention. Although FCS fields **412** and **432** of the presently disclosed embodiments have been described in the context of CRC parity bits, other frame check sequences can be used and are within the scope of the present invention. For example, a check sum can be calculated for the packet and provided in the FCS field.

In an exemplary embodiment, frame format (FMT) fields **414** and **434** contain one control bit which indicates whether the data frame contains only data octets (packet format **410**) or data and padding octets and zero or more messages (packet format **430**). In an exemplary embodiment, a low value for FMT field **414** corresponds to packet format **410**. Alternatively, a high value for FMT field **434** corresponds to packet format **430**.

Sequence number (SEQ) fields **416** and **442** identify the first data unit in data fields **418** and **444**, respectively. The sequence number allows data to be transmitted out of sequence to mobile station **6**, e.g. for retransmission of packets which have been received in error. The assignment of the sequence number at the data unit level eliminates the need for frame fragmentation protocol for retransmission. The sequence number also allows mobile station **6** to detect duplicate data units. Upon receipt of the FMT, SEQ, and LEN fields, mobile station **6** is able to determine which data units have been received at each time slot without the use of special signaling messages.

The number of bits assigned to represent the sequence number is dependent on the maximum number of data units which can be transmitted in one time slot and the worst case data retransmission delays. In an exemplary embodiment, each data unit is identified by a 24-bit sequence number. At the 2.4576 Mbps data rate, the maximum number of data units which can be transmitted at each slot is approximately 256. Eight bits are required to identify

each of the data units. Furthermore, it can be calculated that the worse case data retransmission delays are less than 500 msec. The retransmission delays include the time necessary for a NACK message by mobile station **6**, retransmission of the data, and the number of retransmission attempts caused by the worse case burst error runs. Therefore, 24 bits allows mobile station **6** to properly identify the data units being received without ambiguity. The number of bits in SEQ fields **416** and **442** can be increased or decreased, depending on the size of DATA field **418** and the retransmission delays. The use of different number of bits for SEQ fields **416** and **442** are within the scope of the present invention.

When base station **4** has less data to transmit to mobile station **6** than the space available in DATA field **418**, packet format **430** is used. Packet format **430** allows base station **4** to transmit any number of data units, up to the maximum number of available data units, to mobile station **6**. In an exemplary embodiment, a high value for FMT field **434** indicates that base station **4** is transmitting packet format **430**. Within packet format **430**, LEN field **440** contains the value of the number of data units being transmitted in that packet. In an exemplary embodiment, LEN field **440** is 8 bits in length since DATA field **444** can range from 0 to 255 octets.

DATA fields **418** and **444** contain the data to be transmitted to mobile station **6**. In an exemplary embodiment, for packet format **410**, each data packet comprises 1024 bits of which 992 are data bits. However, variable length data packets can be used to increase the number of information bits and are within the scope of the present invention. For packet format **430**, the size of DATA field **444** is determined by LEN field **440**.

In an exemplary embodiment, packet format **430** can be used to transmit zero or more signaling messages. Signaling length (SIG LEN) field **436** contains the length of the subsequent signaling messages, in octets. In an exemplary embodiment, SIG LEN field **436** is 8 bits in length. SIGNALING field **438** contains the signaling messages. In an exemplary embodiment, each signaling message comprises a message identification (MESSAGE ID) field, a message length (LEN) field, and a message payload, as described below.

PADDING field **446** contains padding octets which, In an exemplary embodiment, are set to 0x00 (hex). PADDING field **446** is used because base station **4** may have fewer data octets to transmit to mobile station **6** than the number of octets available in DATA field **418**. When this occurs, PADDING field **446** contains enough padding octets to fill the unused data field.

PADDING field **446** is variable length and depends on the length of DATA field **444**.

The last field of packet formats **410** and **430** is TAIL fields **420** and **448**, respectively. TAIL fields **420** and **448** contain the zero (0x0) code tail bits which are used to force encoder **114** (see FIG. 3A) into a known state at the end of each data packet. The code tail bits allow encoder **114** to succinctly partition the packet such that only bits from one packet are used in the encoding process. The code tail bits also allow the decoder within mobile station **6** to determine the packet boundaries during the decoding process. The number of bits in TAIL fields **420** and **448** depends on the design of encoder **114**. In an exemplary embodiment, TAIL fields **420** and **448** are long enough to force encoder **114** to a known state.

The two packet formats described above are exemplary formats which can be used to facilitate transmission of data and signaling messages. Various other packet formats can be create to meet the needs of a particular communication system. Also, a communication system can be designed to accommodate more than the two packet formats described above.

IX. Forward Link Control Channel Frame

In one embodiment the traffic channel is also used to transmit messages from base station **4** to mobile stations **6**. The types of messages transmitted include : (1) handoff direction messages, (2) paging messages (e.g. to page a specific mobile station **6** that there is data in the queue for that mobile station **6**), (3) short data packets for a specific mobile station **6**, and (4) ACK or NACK messages for the reverse link data transmissions (to be described later herein). Other types of messages can also be transmitted on the control channel and are within the scope of the present invention. Upon completion of the call set up stage, mobile station **6** monitors the control channel for paging messages and begins transmission of the reverse link pilot signal.

In an exemplary embodiment, the control channel is time multiplexed with the traffic data on the traffic channel, as shown in FIG. 4A. Mobile stations **6** identify the control message by detecting a preamble which as been covered with a predetermined PN code. In an exemplary embodiment, the control messages are transmitted at a fixed rate which is determined by mobile station **6** during acquisition. In the preferred embodiment, the data rate of the control channel is 76.8 Kbps.

The control channel transmits messages in control channel capsules. The diagram of an exemplary control channel capsule is shown in FIG. 4G. In an exemplary embodiment, each capsule comprises preamble **462**, the control payload, and CRC parity bits **474**. The control payload comprises one or more messages and, if necessary, padding bits **472**. Each message comprises message identifier (MSG ID) **464**, message length (LEN) **466**, optional address (ADDR) **468** (e.g., if the message is directed to a specific mobile station 6), and message payload **470**. In an exemplary embodiment, the messages are aligned to octet boundaries. The exemplary control channel capsule illustrated in FIG. 4G comprises two broadcast messages intended for all mobile stations **6** and one message directed at a specific mobile station **6**. MSG ID field **464** determines whether or not the message requires an address field (e.g. whether it is a broadcast or a specific message).

X. Forward Link Pilot Channel

In the presently disclosed embodiments, a forward link pilot channel provides a pilot signal which is used by mobile stations **6** for initial acquisition, phase recovery, timing recovery, and ratio combining. These uses are similar to that of the CDMA communication systems which conform to IS-95 standard. In an exemplary embodiment, the pilot signal is also used by mobile stations **6** to perform the C/I measurement.

A block diagram of an exemplary forward link pilot channel is shown in FIG. 3A. The pilot data comprises a sequence of all zeros (or all ones) which is provided to multiplier **156**. Multiplier **156** covers the pilot data with Walsh code W_0. Since Walsh code W_0 is a sequence of all zeros, the output of multiplier **156** is the pilot data. The pilot data is time multiplexed by MUX **162** and provided to the I Walsh channel which is spread by the short PN_I code within complex multiplier **214** (see FIG. 3B). In an exemplary embodiment, the pilot data is not spread with the long PN code, which is gated off during the pilot burst by MUX **234**, to allow reception by all mobile stations **6**. The pilot signal is thus an unmodulated BPSK signal.

A diagram illustrating the pilot signal is shown in FIG. 4B. In an exemplary embodiment, each time slot comprises two pilot bursts **306a** and **306b** which occur at the end of the first and third quarters of the time slot. In an exemplary embodiment, each pilot burst **306** is 64 chips in duration (Tp=64 chips). In the absence of traffic data or control channel data, base station **4** only

transmits the pilot and power control bursts, resulting in a discontinuous waveform bursting at the periodic rate of 1200 Hz. The pilot modulation parameters are tabulated in Table 4.

XI. Reverse Link Power Control

In the presently disclosed embodiments, the forward link power control channel is used to send the power control command that is used to control the transmit power of the reverse link transmission from remote station **6**. On the reverse link, each transmitting mobile station **6** acts as a source of interference to all other mobile stations **6** in the network. To minimize interference on the reverse link and maximize capacity, the transmit power of each mobile station **6** is controlled by two power control loops. In an exemplary embodiment, the power control loops are similar to that of the CDMA system disclosed in detail in U.S. Patent No. 5,056,109, entitled "METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM", assigned to the assignee of the present invention and incorporated by reference herein. Other power control mechanism can also be contemplated and are within the scope of the present invention.

The first power control loop adjusts the transmit power of mobile station **6** such that the reverse link signal quality is maintained at a set level. The signal quality is measured as the energy-per-bit-to-noise-plus-interference ratio E_b/I_o of the reverse link signal received at base station **4**. The set level is referred to as the E_b/I_o set point. The second power control loop adjusts the set point such that the desired level of performance, as measured by the frame-error-rate (FER), is maintained. Power control is critical on the reverse link because the transmit power of each mobile station **6** is an interference to other mobile stations **6** in the communication system. Minimizing the reverse link transmit power reduces the interference and increases the reverse link capacity.

Within the first power control loop, the E_b/I_o of the reverse link signal is measured at base station **4**. Base station **4** then compares the measured E_b/I_o with the set point. If the measured E_b/I_o is greater than the set point, base station **4** transmits a power control message to mobile station **6** to decrease the transmit power. Alternatively, if the measured E_b/I_o is below the set point, base station **4** transmits a power control message to mobile station **6** to increase the transmit power. In an exemplary embodiment, the power control message is implemented with one power control bit. In an exemplary embodiment, a

high value for the power control bit commands mobile station **6** to increase its transmit power and a low value commands mobile station **6** to decrease its transmit power.

In one embodiment the power control bits for all mobile stations **6** in communication with each base station **4** are transmitted on the power control channel. In an exemplary embodiment, the power control channel comprises up to 32 orthogonal channels which are spread with the 16-bit Walsh covers. Each Walsh channel transmits one reverse power control (RPC) bit or one FAC bit at periodic intervals. Each active mobile station **6** is assigned an RPC index which defines the Walsh cover and QPSK modulation phase (e.g. inphase or quadrature) for transmission of the RPC bit stream destined for that mobile station **6**. In an exemplary embodiment, the RPC index of 0 is reserved for the FAC bit.

A block diagram of an exemplary power control channel is shown in FIG. 3A. The RPC bits are provided to symbol repeater **150** which repeats each RPC bit a predetermined number of times. The repeated RPC bits are provided to Walsh cover element **152** which covers the bits with the Walsh covers corresponding to the RPC indices. The covered bits are provided to gain element **154** which scales the bits prior to modulation so as to maintain a constant total transmit power. In an exemplary embodiment, the gains of the RPC Walsh channels are normalized so that the total RPC channel power is equal to the total available transmit power. The gains of the Walsh channels can be varied as a function of time for efficient utilization of the total base station transmit power while maintaining reliable RPC transmission to all active mobile stations **6**. In an exemplary embodiment, the Walsh channel gains of inactive mobile stations **6** are set to zero. Automatic power control of the RPC Walsh channels is possible using estimates of the forward link quality measurement from the corresponding DRC channel from mobile stations **6**. The scaled RPC bits from gain element **154** are provided to MUX **162**.

In an exemplary embodiment, the RPC indices of 0 through 15 are assigned to Walsh covers W_0 through W_{15}, respectively, and are transmitted around the first pilot burst within a slot (RPC bursts **304** in FIG. 4C). The RPC indices of 16 through 31 are assigned to Walsh covers W_0 through W_{15}, respectively, and are transmitted around the second pilot burst within a slot (RPC bursts **308** in FIG. 4C). In an exemplary embodiment, the RPC bits are BPSK modulated with the even Walsh covers (e.g., W_0, W_2, W_4, etc.) modulated on the inphase signal and the odd Walsh covers (e.g., W_1, W_3, W_5, etc.) modulated on the quadrature signal. To reduce the peak-to-average envelope,

it is preferable to balance the inphase and quadrature power. Furthermore, to minimize cross-talk due to demodulator phase estimate error, it is preferable to assign orthogonal covers to the inphase and quadrature signals.

In an exemplary embodiment, up to 31 RPC bits can be transmitted on 31 RPC Walsh channels in each time slot. In an exemplary embodiment, 15 RPC bits are transmitted on the first half slot and 16 RPC bits are transmitted on the second half slot. The RPC bits are combined by summers **212** (see FIG. 3B) and the composite waveform of the power control channel is as shown is in FIG. 4C.

A timing diagram of the power control channel is illustrated in FIG. 4B. In an exemplary embodiment, the RPC bit rate is 600 bps, or one RPC bit per time slot. Each RPC bit is time multiplexed and transmitted over two RPC bursts (e.g., RPC bursts **304a** and **304b**), as shown in FIGS. 4B and 4C. In an exemplary embodiment, each RPC burst is 32 PN chips (or 2 Walsh symbols) in width (Tpc=32 chips) and the total width of each RPC bit is 64 PN chips (or 4 Walsh symbols). Other RPC bit rates can be obtained by changing the number of symbol repetition. For example, an RPC bit rate of 1200 bps (to support up to 63 mobile stations **6** simultaneously or to increase the power control rate) can be obtained by transmitting the first set of 31 RPC bits on RPC bursts **304a** and **304b** and the second set of 32 RPC bits on RPC bursts **308a** and **308b**. In this case, all Walsh covers are used in the inphase and quadrature signals. The modulation parameters for the RPC bits are summarized in Table 4.

Table 4 - Pilot and Power Control Modulation Parameters

Parameter	RPC	FAC	Pilot	Units
Rate	600	75	1200	Hz
Modulation format	QPSK	QPSK	BPSK	
Duration of control bit	64	1024	64	PN chips
Repeat	4	64	4	symbols

The power control channel has a bursty nature since the number of mobile stations **6** in communication with each base station **4** can be less than the number of available RPC Walsh channels. In this situation, some RPC Walsh channels are set to zero by proper adjustment of the gains of gain element **154**.

In an exemplary embodiment, the RPC bits are transmitted to mobile stations **6** without coding or interleaving to minimize processing delays. Furthermore, the erroneous reception of the power control bit is not detrimental

to the data communication system of the present invention since the error can be corrected in the next time slot by the power control loop.

In the presently disclosed embodiments, mobile stations **6** can be in soft handoff with multiple base stations **4** on the reverse link. A method and apparatus for the reverse link power control for mobile station **6** in soft handoff is disclosed in the aforementioned U.S. Patent No. 5,056,109 and in U.S. Patent No. 5,267,261, which is assigned to the assignee of the present invention and incorporated herein by reference. Mobile station **6** in soft handoff monitors the RPC Walsh channel for each base station **4** in the active set and combines the RPC bits in accordance with the methods disclosed in the aforementioned U.S. Patent No. 5,056,109 and 5,267,261. In the first embodiment, mobile station **6** performs the logic OR of the down power commands. Mobile station **6** decreases the transmit power if any one of the received RPC bits commands mobile station **6** to decrease the transmit power. In the second embodiment, mobile station **6** in soft handoff can combine the soft decisions of the RPC bits before making a hard decision. Other embodiments for processing the received RPC bits can be contemplated and are within the scope of the present invention.

In one embodiment the FAC bit indicates to mobile stations **6** whether or not the traffic channel of the associated pilot channel will be transmitting on the next half frame. The use of the FAC bit improves the C/I estimate by mobile stations **6**, and hence the data rate request, by broadcasting the knowledge of the interference activity. In an exemplary embodiment, the FAC bit only changes at half frame boundaries and is repeated for eight successive time slots, resulting in a bit rate of 75 bps. The parameters for the FAC bit is listed in Table 4.

Using the FAC bit, mobile stations **6** can compute the C/I measurement as follows:

$$\left(\frac{C}{I}\right)_i = \frac{C_i}{I - \sum_{j \neq i} (1 - \alpha_j) C_j} \quad , \tag{3}$$

where $(C/I)_i$ is the C/I measurement of the i^{th} forward link signal, C_i is the total received power of the i^{th} forward link signal, C_j is the received power of the j^{th} forward link signal, I is the total interference if all base stations **4** are transmitting, α_j is the FAC bit of the j^{th} forward link signal and can be 0 or 1 depending on the FAC bit.

XII. Reverse Link Data Transmission

In the presently disclosed embodiments, the reverse link supports variable rate data transmission. The variable rate provides flexibility and allows mobile stations **6** to transmit at one of several data rates, depending on the amount of data to be transmitted to base station **4**. In an exemplary embodiment, mobile station **6** can transmit data at the lowest data rate at any time. In an exemplary embodiment, data transmission at higher data rates requires a grant by base station 4. This implementation minimizes the reverse link transmission delay while providing efficient utilization of the reverse link resource.

An exemplary illustration of a flow diagram of reverse link data transmission is shown in FIG. 8. Initially, at slot n, mobile station **6** performs an access probe, as described in the aforementioned U.S. Patent No. 5,289,527, to establish the lowest rate data channel on the reverse link at block **802**. In the same slot n, base station **4** demodulates the access probe and receives the access message at block **804**. Base station **4** grants the request for the data channel and, at slot n+2, transmits the grant and the assigned RPC index on the control channel, at block **806**. At slot n+2, mobile station **6** receives the grant and is power controlled by base station **4**, at block **808**. Beginning at slot n+3, mobile station **6** starts transmitting the pilot signal and has immediate access to the lowest rate data channel on the reverse link.

If mobile station **6** has traffic data and requires a high rate data channel, mobile station **6** can initiate the request at block **810**. At slot n+3, base station **4** receives the high speed data request, at block **812**. At slot n+5, base station **4** transmits the grant on the control channel, at block **814**. At slot n+5, mobile station **6** receives the grant at block **816** and begins high speed data transmission on the reverse link starting at slot n+6, at block **818**.

XIII. Reverse Link Architecture

In the data communication system of the presently disclosed embodiments, the reverse link transmission differs from the forward link transmission in several ways. On the forward link, data transmission typically occurs from one base station **4** to one mobile station **6**. However, on the reverse link, each base station **4** can concurrently receive data transmissions from multiple mobile stations **6**. In an exemplary embodiment, each mobile station **6**

can transmit at one of several data rates depending on the amount of data to be transmitted to base station **4**. This system design reflects the asymmetric characteristic of data communication.

In an exemplary embodiment, the time base unit on the reverse link is identical to the time base unit on the forward link. In an exemplary embodiment, the forward link and reverse link data transmissions occur over time slots which are 1.667 msec in duration. However, since data transmission on the reverse link typically occurs at a lower data rate, a longer time base unit can be used to improve efficiency.

In an exemplary embodiment, the reverse link supports two channels: the pilot/DRC/RRI channel and the data channel. The function and implementation of each of these channel are described below. The pilot/DRC/RRI channel is used to transmit the pilot signal, the DRC messages, and the RRI symbols (described below), and the data channel is used to transmit traffic data. The RRI (reverse rate indicator) indicates the rate of the reverse link traffic channel.

A diagram of an exemplary reverse link frame structure is illustrated in FIG. 7A. In an exemplary embodiment, the reverse link frame structure is similar to the forward link frame structure shown in FIG. 4A. However, on the reverse link, the pilot/DRC/RRI data and traffic data are transmitted concurrently on the inphase and quadrature channels. In one embodiment each slot is 2048 chips long, the pilot signal being time multiplexed on alternating 64-chip intervals with the DRC message. The RRI channel symbol is punctured into the pilot for one-sixteenth of the pilot symbols (one-thirty-second of the slot), or one 64-chip interval, per slot.

In an exemplary embodiment, mobile station **6** transmits a DRC message on the pilot/DRC/RRI channel at each time slot whenever mobile station **6** is receiving high speed data transmission. Alternatively, when mobile station **6** is not receiving high speed data transmission, the entire slot on the pilot/DRC/RRI channel comprises the pilot signal. The pilot signal is used by the receiving base station **4** for a number of functions: as an aid to initial acquisition, as a phase reference for the pilot/DRC and the data channels, and as the source for the closed loop reverse link power control.

In an exemplary embodiment, the bandwidth of the reverse link is selected to be 1.2288 MHz. This bandwidth selection allows the use of existing hardware designed for a CDMA system which conforms to the IS-95 standard. However, other bandwidths can be utilized to increase capacity and/or to conform to system requirements. In an exemplary embodiment, the same long

PN code and short PN_I and PN_Q codes as those specified by the IS-95 standard are used to spread the reverse link signal. In an exemplary embodiment, the reverse link channels are transmitted using QPSK modulation. Alternatively, OQPSK modulation can be used to minimize the peak-to-average amplitude variation of the modulated signal which can result in improved performance. The use of different system bandwidth, PN codes, and modulation schemes can be contemplated and are within the scope of the present invention.

In an exemplary embodiment, the transmit power of the reverse link transmissions on the pilot/DRC/RRI channel and the data channel are controlled such that the E_b/I_o of the reverse link signal, as measured at base station **4**, is maintained at a predetermined E_b/I_o set point as discussed in the aforementioned U.S. Patent No. 5,506,109. The power control is maintained by base stations **4** in communication with the mobile station **6** and the commands are transmitted as the RPC bits as discussed above.

XIV. Reverse Link Data Channel

A block diagram of an exemplary reverse link architecture is shown in FIG. 6. The data is partitioned into data packets and provided to encoder **612**. For each data packet, encoder **612** generates the CRC parity bits, inserts the code tail bits, and encodes the data. In an exemplary embodiment, encoder **612** encodes the packet in accordance with the encoding format disclosed in the aforementioned U.S. Patent Application Serial No. 08/743,688. Other encoding formats can also be used and are within the scope of the present invention. The encoded packet from encoder **612** is provided to block interleaver **614** which reorders the code symbols in the packet. The interleaved packet is provided to multiplier **616** which covers the data with the Walsh cover and provides the covered data to gain element **618**. Gain element **618** scales the data to maintain a constant energy-per-bit E_b regardless of the data rate. The scaled data from gain element **618** is provided to multipliers **650b** and **650d** which spread the data with the PN_Q and PN_I sequences, respectively. The spread data from multipliers **650b** and **650d** are provided to filters **652b** and **652d**, respectively, which filter the data. The filtered signals from filters **652a** and **652b** are provided to summer **654a** and the filtered signals from filter **652c** and **652d** are provided to summer **654b**. Summers **654** sum the signals from the data channel with the signals from the pilot/DRC/RRI channel. The outputs of summers **654a** and **654b** comprise IOUT and QOUT, respectively, which are modulated

with the inphase sinusoid COS($w_c t$) and the quadrature sinusoid SIN($w_c t$), respectively (as in the forward link), and summed (not shown in FIG. 6). In an exemplary embodiment, the traffic data is transmitted on both the inphase and quadrature phase of the sinusoid.

In an exemplary embodiment, the data is spread with the long PN code and the short PN codes. The long PN code scrambles the data such that the receiving base station **4** is able to identify the transmitting mobile station **6**. The short PN code spreads the signal over the system bandwidth. The long PN sequence is generated by long code generator **642** and provided to multipliers **646**. The short PN_I and PN_Q sequences are generated by short code generator **644** and also provided to multipliers **646a** and **646b**, respectively, which multiply the two sets of sequences to form the PN_I and PN_Q signals, respectively. Timing/control circuit **640** provides the timing reference.

The exemplary block diagram of the data channel architecture as shown in FIG. 6 is one of numerous architectures that support data encoding and modulation on the reverse link. For high rate data transmission, an architecture similar to that of the forward link utilizing multiple orthogonal channels can also be used. Other architectures, such as the architecture for the reverse link traffic channel in the CDMA system which conforms to the IS-95 standard, can also be contemplated and are within the scope of the present invention.

In an exemplary embodiment, the reverse link data channel supports four data rates that are tabulated in Table 5. Additional data rates and/or different data rates can be supported and are within the scope of the present invention. In an exemplary embodiment, the packet size for the reverse link is dependent on the data rate, as shown in Table 5. As described in the aforementioned U.S. Patent No. 5,933,462, improved decoder performance can be obtained for larger packet sizes. Thus, different packet sizes than those listed in Table 5 can be utilized to improve performance and are within the scope of the present invention. In addition, the packet size can be made a parameter which is independent of the data rate.

Table 5 - Pilot and Power Control Modulation Parameters

Parameter	Data rates				Units
	9.6	19.2	38.4	76.8	Kbps
Frame duration	26.66	26.66	13.33	13.33	Msec
Data packet length	245	491	491	1003	Bits

CRC length	16	16	16	16	Bits
Code tail bits	5	5	5	5	Bits
Total bits/packet	256	512	512	1024	Bits
Encoded packet length	1024	2048	2048	4096	Symbols
Walsh symbol length	32	16	8	4	Chips
Request required	no	yes	yes	yes	

As shown in Table 5, the reverse link supports a plurality of data rates. In an exemplary embodiment, the lowest data rate of 9.6K bps is allocated to each mobile station **6** upon registration with base station **4**. In an exemplary embodiment, mobile stations **6** can transmit data on the lowest rate data channel at any time slot without having to request permission from base station **4**. In an exemplary embodiment, data transmission at the higher data rates are granted by the selected base station **4** based on a set of system parameters such as the system loading, fairness, and total throughput. An exemplary scheduling mechanism for high speed data transmission is described in detail in the aforementioned U.S. Patent Application Serial No. 08/798,951.

XV. Reverse Link Pilot/DRC/RRI Channel

An exemplary block diagram of the pilot/DRC/RRI channel is shown in FIG. 6. The DRC message is provided to DRC encoder **626**, which encodes the message in accordance with a predetermined coding format. Coding of the DRC message is important since the error probability of the DRC message needs to be sufficiently low because incorrect forward link data rate determination impacts the system throughput performance. In an exemplary embodiment, DRC encoder **626** is a rate (8,4) orthogonal block encoder that encodes the 3-bit DRC message into an 8-bit code word. The encoded DRC message is provided to multiplier **628** which covers the message with the Walsh code that uniquely identifies the destination base station **4** for which the DRC message is directed. The Walsh code is provided by Walsh generator **624**. The covered DRC message is provided to multiplexer (MUX) **630**, which multiplexes the DRC message with the pilot data, and then multiplied by an 8-chip Walsh cover (not shown). After being multiplexed by MUX **630**, the pilot data is also multiplied by the same 8-chip Walsh cover (not shown). The RRI symbol is provided to RRI encoder **627**, which encodes the RRI symbol in accordance with one embodiment as described below with reference to FIG. 11.

The encoded RRI symbol is provided to MUX **630**, which multiplexes the RRI symbol with the DRC message and the pilot data, and then multiplied by the same 8-chip Walsh cover (not shown). The RRI message, the DRC message, and the pilot data are provided to multipliers **650a** and **650c** which spread the data with the PN_I and PN_Q signals, respectively. Thus, the pilot data, the RRI symbol, and the DRC message are transmitted on both the inphase and quadrature phase of the sinusoid. The 8-chip Walsh cover is advantageously a predefined Walsh function. In one embodiment the all-zeros Walsh function is used. In an alternate embodiment, the 8-chip Walsh cover may be multiplied by the pilot data, the RRI symbol, and the DRC message signals before the pilot data, the RRI symbol, and the DRC message signals are multiplexed by MUX **630**.

In an exemplary embodiment, the DRC message is transmitted to the selected base station **4**. This is achieved by covering the DRC message with the Walsh code that identifies the selected base station **4**. In an exemplary embodiment, the Walsh code is 128 chips in length. The derivation of 128-chip Walsh codes is known in the art. One unique Walsh code is assigned to each base station **4** that is in communication with mobile station **6**. Each base station **4** decovers the signal on the DRC channel with its assigned Walsh code. The selected base station **4** is able to decover the DRC message and transmits data to the requesting mobile station **6** on the forward link in response thereto. Other base stations **4** are able to determine that the requested data rate is not directed to them because these base stations **4** are assigned different Walsh codes.

In an exemplary embodiment, the reverse link short PN codes for all base stations **4** in the data communication system are the same and there is no offset in the short PN sequences to distinguish different base stations **4**. The data communication system advantageously supports soft handoff on the reverse link. Using the same short PN codes with no offset allows multiple base stations **4** to receive the same reverse link transmission from mobile station **6** during a soft handoff. The short PN codes provide spectral spreading but do not allow for identification of base stations **4**.

In an exemplary embodiment, the DRC message carries the requested data rate by mobile station **6**. In the alternative embodiment, the DRC message carries an indication of the forward link quality (e.g., the C/I information as measured by mobile station **6**). Mobile station **6** can simultaneously receive the forward link pilot signals from one or more base stations **4** and performs the C/I measurement on each received pilot signal. Mobile station **6** then selects the best base station **4** based on a set of parameters that can comprise present

and previous C/I measurements. The rate control information is formatted into the DRC message which can be conveyed to base station **4** in one of several embodiments.

In the first embodiment, mobile station **6** transmits a DRC message based on the requested data rate. The requested data rate is the highest supported data rate which yields satisfactory performance at the C/I measured by mobile station **6**. From the C/I measurement, mobile station **6** first calculates the maximum data rate which yields satisfactory performance. The maximum data rate is then quantized to one of the supported data rates and designated as the requested data rate. The data rate index corresponding to the requested data rate is transmitted to the selected base station **4**. An exemplary set of supported data rates and the corresponding data rate indices are shown in Table 1.

In the second embodiment, wherein mobile station **6** transmits an indication of the forward link quality to the selected base station **4**, mobile station **6** transmits a C/I index which represents the quantized value of the C/I measurement. The C/I measurement can be mapped to a table and associated with a C/I index. Using more bits to represent the C/I index allows a finer quantization of the C/I measurement. Also, the mapping can be linear or predistorted. For a linear mapping, each increment in the C/I index represents a corresponding increase in the C/I measurement. For example, each step in the C/I index can represent a 2.0 dB increase in the C/I measurement. For a predistorted mapping, each increment in the C/I index can represent a different increase in the C/I measurement. As an example, a predistorted mapping can be used to quantize the C/I measurement to match the cumulative distribution function (CDF) curve of the C/I distribution as shown in FIG. 10.

Other embodiments to convey the rate control information from mobile station **6** to base station 4 can be contemplated and are within the scope of the present invention. Furthermore, the use of different number of bits to represent the rate control information is also within the scope of the present invention. Throughout much of the specification, the presently disclosed embodiments are described in the context of the first embodiment, the use of a DRC message to convey the requested data rate, for simplicity.

In an exemplary embodiment, the C/I measurement can be performed on the forward link pilot signal in the manner similar to that used in the CDMA system. A method and apparatus for performing the C/I measurement is disclosed in U.S. Patent No. 5,903,554, entitled "METHOD AND APPARATUS FOR MEASURING LINK QUALITY IN A SPREAD SPECTRUM COMMUNICATION SYSTEM", issued May 11, 1999, assigned to the assignee

of the present invention and incorporated by reference herein. In summary, the C/I measurement on the pilot signal can be obtained by despreading the received signal with the short PN codes. The C/I measurement on the pilot signal can contain inaccuracies if the channel condition changed between the time of the C/I measurement and the time of actual data transmission. In one embodiment the use of the FAC bit allows mobile stations **6** to take into consideration the forward link activity when determining the requested data rate.

In the alternative embodiment, the C/I measurement can be performed on the forward link traffic channel. The traffic channel signal is first despread with the long PN code and the short PN codes and decovered with the Walsh code. The C/I measurement on the signals on the data channels can be more accurate because a larger percentage of the transmitted power is allocated for data transmission. Other methods to measure the C/I of the received forward link signal by mobile station **6** can also be contemplated and are within the scope of the present invention.

In an exemplary embodiment, the DRC message is transmitted in the first half of the time slot (see FIG. 7A). For an exemplary time slot of 1.667 msec, the DRC message comprises the first 1024 chips or 0.83 msec of the time slot. The remaining 1024 chips of time are used by base station **4** to demodulate and decode the message. Transmission of the DRC message in the earlier portion of the time slot allows base station **4** to decode the DRC message within the same time slot and possibly transmit data at the requested data rate at the immediate successive time slot. The short processing delay allows the communication system of the present invention to quickly adapt to changes in the operating environment.

In the alternative embodiment, the requested data rate is conveyed to base station **4** by the use of an absolute reference and a relative reference. In this embodiment, the absolute reference comprising the requested data rate is transmitted periodically. The absolute reference allows base station **4** to determine the exact data rate requested by mobile station **6**. For each time slot between transmissions of the absolute references, mobile station **6** transmits a relative reference to base station **4** which indicates whether the requested data rate for the upcoming time slot is higher, lower, or the same as the requested data rate for the previous time slot. Periodically, mobile station **6** transmits an absolute reference. Periodic transmission of the data rate index allows the requested data rate to be set to a known state and ensures that erroneous receptions of relative references do not accumulate. The use of absolute

references and relative references can reduce the transmission rate of the DRC messages to base station **6**. Other protocols to transmit the requested data rate can also be contemplated and are within the scope of the present invention.

XVI. Reverse Link RRI Encoding

In an exemplary embodiment, the RRI encoder **627** includes an encoder **1002** coupled to a code word repetition generator **1004**. One 3-bit RRI symbol per 16-slot packet is provided to the encoder **1002**. In one embodiment the encoder **1002** is a (32,3) linear block encoder. The encoder **1002** generates thirty-two binary RRI symbols per packet, as described below, and provides the encoded RRI symbols to the code word repetition generator **1004**. In one embodiment the code word repetition generator **1004** is configured to perform factor 4 repetition of the encoded RRI symbols, thereby generating 128 binary RRI symbols per packet. The encoded, repeated RRI symbols are provided to the MUX **630**, which multiplexes the RRI symbols with the pilot symbols and the DCR symbols. The multiplexed data stream output from the MUX **630** is provided to signal point mapping logic **1006**, which, in accordance with one embodiment, maps digital zeros to +1 values and digital ones to –1 values. The signal point mapping logic **1006** provides the multiplexed pilot, DRC, and RRI values to a multiplier **1008**. The multiplier **1008** also receives an 8-chip Walsh function, which is advantageously a predefined Walsh function of eight plus one values. In one embodiment the multiplier **1008** multiplies the Walsh function with the multiplexed pilot, DRC, and RRI values to produce an output data stream at a chip rate of 1.2288 megachips per second.

The RRI encoder **627** thus performs (128,3) encoding comprising a (32,3) linear encoding followed by code word repetition with a repetition factor of four. Advantageously, no puncturing is necessary. All repetitions are code word repetitions. The (32,3) code has a weight distribution with one code word of wieght zero, six code words of weight eighteen, and one code words of weight twenty. After four repetitions the weights are four times higher. Those of skill in the art would understand that (n,k) encoding (or (n,k) coding) indicates that k bits are encoded to produce n symbols, n being greater than k, with a code rate of k/n. Those of skill would also appreciate that the weight of a given code word is equal to the sum of the number of digital ones in the code word. The (32,3) linear code may be described in terms of the following 3 x 32 generator matrix, **G**:

$$\mathbf{G} = \begin{bmatrix} g_{29} \cdots g_1 & g_0 & 0 & 0 \\ 0 & g_{29} \cdots g_1 & g_0 & 0 \\ 0 & 0 & g_{29} \cdots & g_1 & g_0 \end{bmatrix}.$$

In the generator matrix, **G**, the thirty symbols g_{29} through g_0 (from left to right) in any of the three rows may be denoted **g**. It can be seen that the first row of the generator matrix, **G**, is simply **g** 0 0. The second row is 0 **g** 0. The third row is 0 0 **g**. In one embodiment the binary value of **g** is equal to 2492DBBF in hexadecimal notation. The eight code words are all eight combinations of the rows of the generator matrix, **G**, with bit-by-bit exclusive-OR (XOR) combining (i.e., summing mod 2) of the rows, with appropriate rows being on or off based upon the 3-bit input RRI symbol values. In accordance with one embodiment, the mapping is shown below in Table 6, wherein the left column indicates 3-bit input RRI symbol values and the right column indicates associated code words output from the encoder **1002**, and wherein the bottom row of the generator matrix, **G**, may be used as **g**.

Table 6: RRI (32,3) Encoder Mapping

RRI Input Symbol	Encoder Output Codeword
000	0
001	**g**
010	2**g**
011	2**g** ⊕ **g**
100	4**g**
101	4**g** ⊕ **g**
110	4**g** ⊕ 2**g**
111	4**g** ⊕ 2**g** ⊕ **g**

g = 2492DBBF in hexadecimal notation
⊕ indicates bit-by-bit exclusive-OR of 32-bit values

The particular value of **g** is advantageously selected to achieve the largest possible distance between different code words. The distance between code words is the number of output symbol positions in which the two code words are different. A larger distance makes it easier to distinguish between the two code words in the presence of noise. For the (32,3) linear block code, the largest possible distance between different code words is eighteen, as

described by A.E. Brouwer & T. Verhoeff, "An Updated Table of Minimum-Distance Bounds for Binary Codes," *IEEE Trans. on Information Theory*, Vol. 39, No. 2, Mar. 1993, at 662-677. After repetition by four, the distance is seventy-two in a (128,3) code. (Recall that the above-described (32,3) code, after repetition of code words by four, has a weight distribution of one code word with weight zero, six code words with weight seventy-two (eighteen times four), and one code word with weight eighty (twenty times four).)

Those skilled in the art would recognize that other block sizes and repetition factors could be employed (either larger block sizes with smaller repetition factors or smaller block sizes with larger repetition factors). In one embodiment a (128,3) code is formed using an (8,3) linear block code and a repetition factor of sixteen, yielding a distance of sixty-four. In another embodiment a (128,3) code is formed using a (16,3) linear block code and a repetition factor of eight, yielding a distance of sixty-four. In the embodiment described above with reference to FIG. 11, a (128,3) code is formed using a (32,3) linear block code and a repetition factor of four, yielding a distance of seventy-two. In another embodiment a (128,3) code is formed using a (64,3) linear block code and a repetition factor of two, yielding a distance of seventy-two. In another embodiment a (128,3) code is formed using no repetition, yielding a distance of seventy-two. In another embodiment, as described below, a (133,3) code is formed using a (7,3) linear block code and a repetition factor of nineteen (yielding a minimum distance of seventy-six). The (133,3) code is then punctured at five specified symbol locations to produce a (128,3).

In the final alternate embodiment mentioned above, RRI symbols are provided to a (7,3) simplex encoder. The (7,3) simplex encoder is advantageously constructed from an orthogonal code by puncturing the first symbol of every code word. The encoded symbols are then provided to a code word repetition generator with a repetition factor of nineteen. The output from the code word repetition generator is provided to symbol puncturing logic, which performs five-symbol puncturing on preselected symbols in each code word. A disadvantage of this embodiment is that puncturing (and hence greater coder complexity) is required to achieve a (128,3) code.

XVII. Reverse Link Access Channel

The access channel is used by mobile station **6** to transmit messages to base station **4** during the registration phase. In an exemplary embodiment, the

access channel is implemented using a slotted structure, as shown in FIG. 7B, with each slot being accessed at random by mobile station **6**. In an exemplary embodiment, the access channel is time multiplexed with the DRC channel.

In an exemplary embodiment, the access channel transmits messages in access channel capsules. In an exemplary embodiment, the access channel frame format is identical to that specified by the IS-95 standard, except that the timing is in 26.67 msec frames instead of the 20 msec frames specified by IS-95 standard. The diagram of an exemplary access channel capsule is shown in FIG. 7B. In an exemplary embodiment, each access channel capsule **712** comprises preamble **722**, one or more message capsules **724**, and padding bits **726**. Each message capsule **724** comprises message length (MSG LEN) field **732**, message body **734**, and CRC parity bits **736**.

XVIII. Reverse Link NACK Channel

In one embodiment mobile station **6** transmits NACK messages on the data channel. A NACK message is generated for each packet received in error by mobile station **6**. In an exemplary embodiment, the NACK messages can be transmitted using the Blank and Burst signaling data format as disclosed in the aforementioned U.S. Patent No. 5,504,773.

Although the presently disclosed embodiments have been described in the context of a NACK protocol, the use of an ACK protocol can be contemplated and is within the scope of the present invention.

XIX. Conclusion

Thus, a novel and improved maximum-distance, rate 3/128 block coding scheme has been described. In the embodiments herein described, the mobile station **6** may also be referred to as a subscriber unit. A subscriber unit may be, e.g., a wireless telephone, personal digital assistant (PDA), a laptop computer, a phone connected to a computer, a handset coupled to a hands-free car kit, or any other known form of access terminal. Those of skill in the art would understand that the data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description are advantageously represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof. Those of skill would further appreciate that the various illustrative

logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. The various illustrative components, blocks, modules, circuits, and steps have been described generally in terms of their functionality. Whether the functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans recognize the interchangeability of hardware and software under these circumstances, and how best to implement the described functionality for each particular application. As examples, the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented or performed with a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components such as, e.g., registers and FIFO, a processor executing a set of firmware instructions, any conventional programmable software module and a processor, or any combination thereof designed to perform the functions described herein. The processor may advantageously be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. The software module could reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary processor is advantageously coupled to the storage medium so as to read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may reside in a telephone. In the alternative, the processor and the storage medium may reside in a telephone. The processor may be implemented as a combination of a DSP and a microprocessor, or as two microprocessors in conjunction with a DSP core, etc.

The previous description of the preferred embodiments is provided to enable any person skilled in the art to make or use the present invention. The various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without the use of the inventive faculty. Thus, the present invention is not intended to be limited to the embodiments shown herein but is

to be accorded the widest scope consistent with the principles and novel features disclosed herein.

WHAT IS CLAIMED IS:

CLAIMS

1. A method of encoding data, comprising:
block encoding the data to generate a plurality of code words; and
repeating each code word a predefined number of times.

2. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and thirty-two columns.

3. The method of claim 1, wherein the predefined number of times is four.

4. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and thirty-two columns, and wherein the predefined number is four.

5. The method of claim 4, wherein each row of the matrix comprises two zeros and a binary number having a hexadecimal value of 2492DBBF.

6. The method of claim 5, wherein the first row of the matrix from left to right is the binary number having a hexadecimal value of 2492DBBF followed by the two zeros, the second row of the matrix from left to right is a first of the two zeros followed by the binary number having a hexadecimal value of 2492DBBF followed by a second of the two zeros, and the third row of the matrix from left to right is the two zeros followed by the binary number having a hexadecimal value of 2492DBBF.

7. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and eight columns, and wherein the predefined number is sixteen.

8. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and sixteen columns, and wherein the predefined number is eight.

9. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and sixty-four columns, and wherein the predefined number is two.

10. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and 128 columns, and wherein the predefined number is zero.

11. The method of claim 1, wherein the block encoding comprises encoding the data as a matrix of three rows and seven columns, and wherein the predefined number is nineteen, the method further comprising puncturing each set of repeated code words in five locations.

12. The method of claim 1, wherein the data comprises a transmit data rate indicator from a subscriber unit in a data communication system.

13. The method of claim 12, further comprising multiplexing the encoded, repeated rate indicator data with an encoded rate request message and a pilot signal to generate a multiplexed signal.

14. The method of claim 13, further comprising covering the multiplexed signal with an orthogonal code.

15. The method of claim 14, wherein the orthogonal code is a Walsh function having eight chips.

16. A subscriber unit, comprising:

means for block encoding data to generate a plurality of code words; and

means for repeating each code word a predefined number of times.

17. The subscriber unit of claim 16, wherein the means for block encoding comprises means for encoding the data as a matrix of three rows and thirty-two columns, the predefined number is four, and the first row of the matrix from left to right is a binary number having a hexadecimal value of 2492DBBF followed by two zeros, the second row of the matrix from left to right is a first zero followed by the binary number having a hexadecimal value of 2492DBBF followed by a second zero, and the third row of the matrix from left to right is two zeros followed by the binary number having a hexadecimal value of 2492DBBF.

18. A subscriber unit, comprising:
a processor; and
a storage medium coupled to the processor and containing a set of instructions executable by the processor to block encode data to generate a plurality of code words, and repeat each code word a predefined number of times.

19. The subscriber unit of claim 18, wherein the set of instructions is further executable by the processor to repeat each code word four times, and encode the data as a matrix of three rows and thirty-two columns, the first row of the matrix from left to right being a binary number having a hexadecimal value of 2492DBBF followed by two zeros, the second row of the matrix from left to right being a first zero followed by the binary number having a hexadecimal value of 2492DBBF followed by a second zero, and the third row of the matrix from left to right being two zeros followed by the binary number having a hexadecimal value of 2492DBBF.

20. A data transmission system, comprising:
a block encoder; and
a code word repetition generator coupled to the block encoder.

21. The data transmission system of claim 20, wherein the block encoder comprises a (32,3) linear block encoder configured to generate at least one code word by encoding data as a matrix of three rows and thirty-two columns, and wherein the code word repetition generator is configured to repeat each code word a predefined number of times.

22. The data transmission system of claim 21, wherein the code word repetition generator is configured to repeat each code word four times.

23. The data transmission system of claim 22, wherein each row of the matrix comprises two zeros and a binary number having a hexadecimal value of 2492DBBF.

24. The data transmission system of claim 23, wherein the first row of the matrix from left to right is the binary number having a hexadecimal value of 2492DBBF followed by the two zeros, the second row of the matrix from left to right is a first of the two zeros followed by the binary number having a

hexadecimal value of 2492DBBF followed by a second of the two zeros, and the third row of the matrix from left to right is the two zeros followed by the binary number having a hexadecimal value of 2492DBBF.

25. The data transmission system of claim 20, wherein the block encoder comprises an (8,3) linear block encoder configured to generate at least one code word by encoding data as a matrix of three rows and eight columns, and wherein the code word repetition generator is configured to repeat each code word sixteen times.

26. The data transmission system of claim 20, wherein the block encoder comprises a (16,3) linear block encoder configured to generate at least one code word by encoding data as a matrix of three rows and sixteen columns, and wherein the code word repetition generator is configured to repeat each code word eight times.

27. The data transmission system of claim 20, wherein the block encoder comprises a (64,3) linear block encoder configured to generate at least one code word by encoding data as a matrix of three rows and sixty-four columns, and wherein the code word repetition generator is configured to repeat each code word two times.

28. The data transmission system of claim 20, wherein the block encoder comprises a (128,3) linear block encoder configured to generate at least one code word by encoding data as a matrix of three rows and 128 columns, and wherein the code word repetition generator is configured to repeat each code word zero times.

29. The data transmission system of claim 20, wherein the block encoder comprises a (7,3) linear block encoder configured to generate at least one code word by encoding data as a matrix of three rows and seven columns, and wherein the code word repetition generator is configured to generate at least one set of repeated code words by repeating the at least one code word nineteen times, the data transmission system further comprising a symbol puncturing element coupled to the code word repetition generator and configured to puncture the at least one set of repeated code words in five locations.

30. The data transmission system of claim 21, wherein the data comprises a transmit data rate indicator from a subscriber unit in a data communication system, the data transmission system residing in the subscriber unit.

31. The data transmission system of claim 30, further comprising a multiplexer coupled to the code word repetition generator and configured to multiplex the encoded, repeated rate indicator data with an encoded rate request message and a pilot signal to generate a multiplexed signal.

32. The data transmission system of claim 31, further comprising a multiplier coupled to the multiplexer and configured to multiply each bit of the multiplexed signal by an orthogonal code.

33. The data transmission system of claim 32, wherein the orthogonal code is a Walsh function having eight chips.

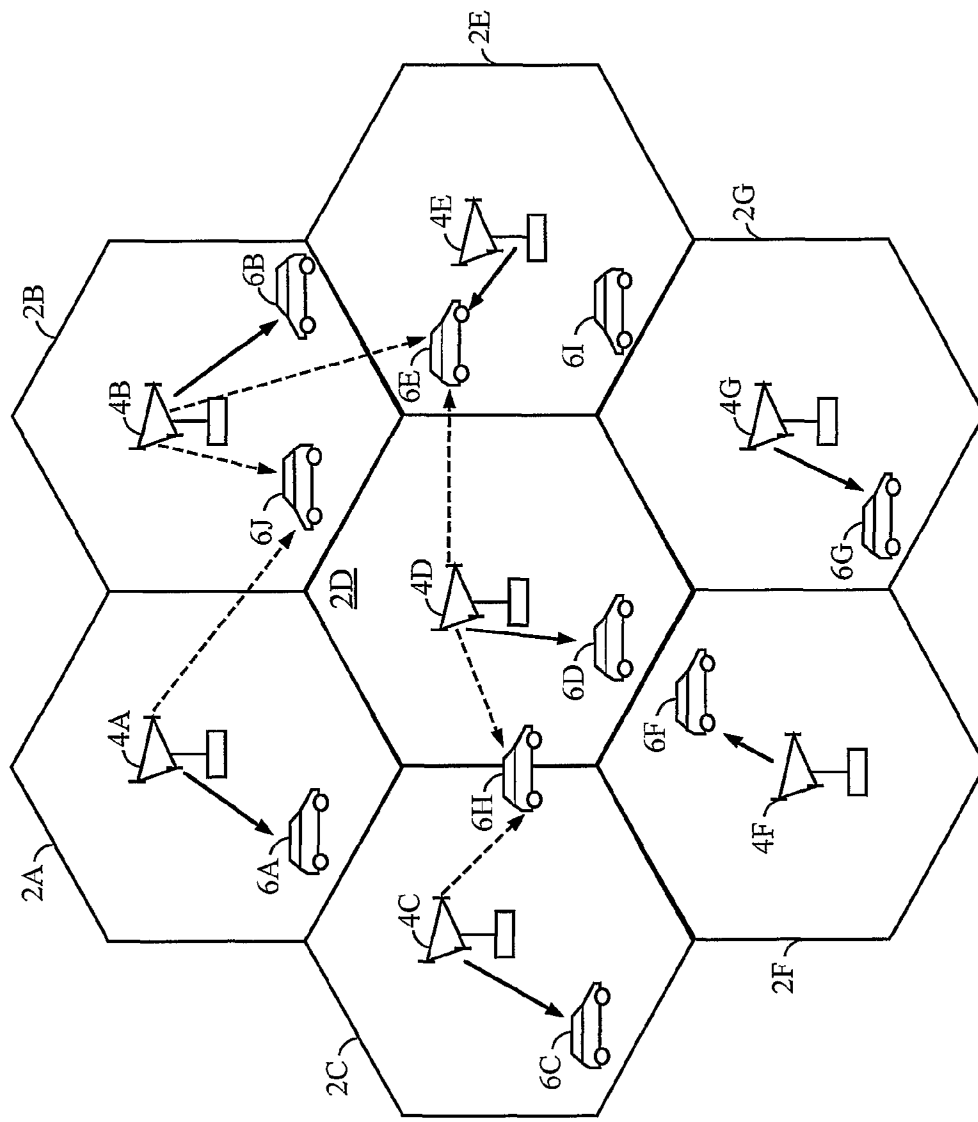

FIG. 1

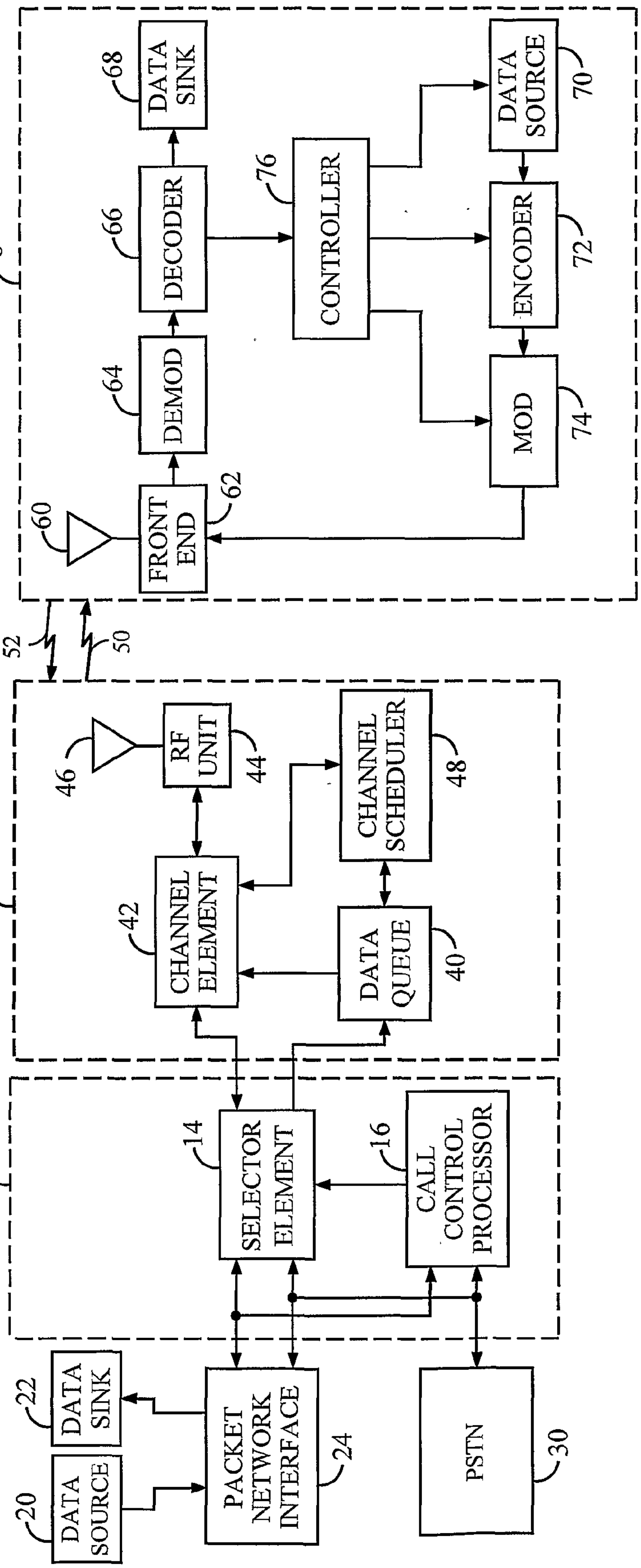
6
DATA SINK
68
DECODER
66
DEMOD
64
FRONT END
60
62
CONTROLLER
76
DATA SOURCE
70
ENCODER
72
MOD
74
52
50
4
RF UNIT
46
44
CHANNEL SCHEDULER
48
CHANNEL ELEMENT
42
DATA QUEUE
40
10
SELECTOR ELEMENT
14
CALL CONTROL PROCESSOR
16
DATA SINK
22
DATA SOURCE
20
PACKET NETWORK INTERFACE
24
PSTN
30

FIG. 2

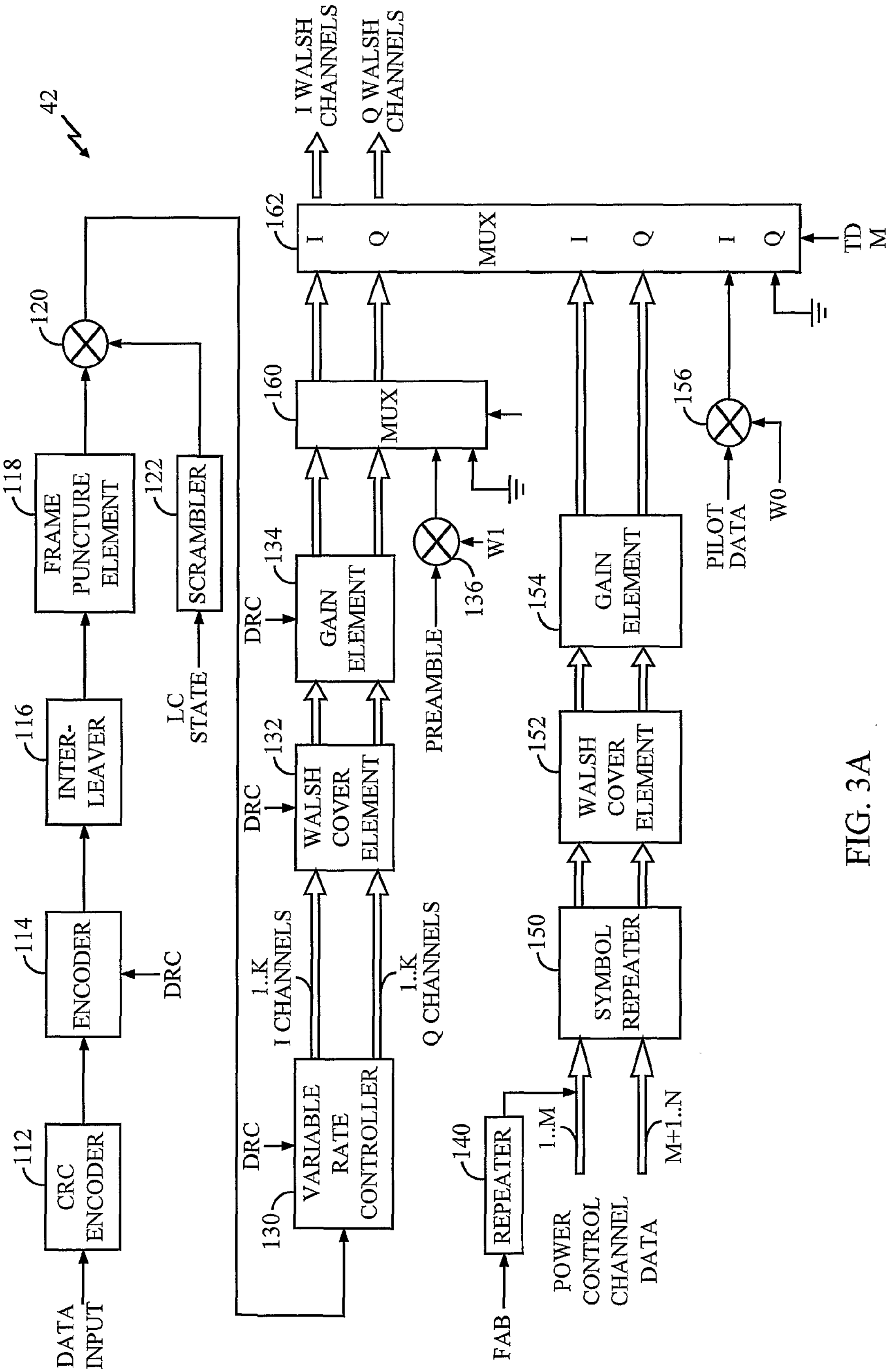
42
DATA INPUT
112
CRC ENCODER
114
ENCODER
DRC
116
INTER-LEAVER
118
FRAME PUNCTURE ELEMENT
120
122
SCRAMBLER
LC STATE
130
VARIABLE RATE CONTROLLER
DRC
1..K I CHANNELS
1..K Q CHANNELS
132
WALSH COVER ELEMENT
DRC
134
GAIN ELEMENT
DRC
136
W1
PREAMBLE
160
MUX
162
I
Q
MUX
I
Q
I
Q
TDM
I WALSH CHANNELS
Q WALSH CHANNELS
140
REPEATER
FAB
POWER CONTROL CHANNEL DATA
1..M
M+1..N
150
SYMBOL REPEATER
152
WALSH COVER ELEMENT
154
GAIN ELEMENT
156
PILOT DATA
W0

FIG. 3A

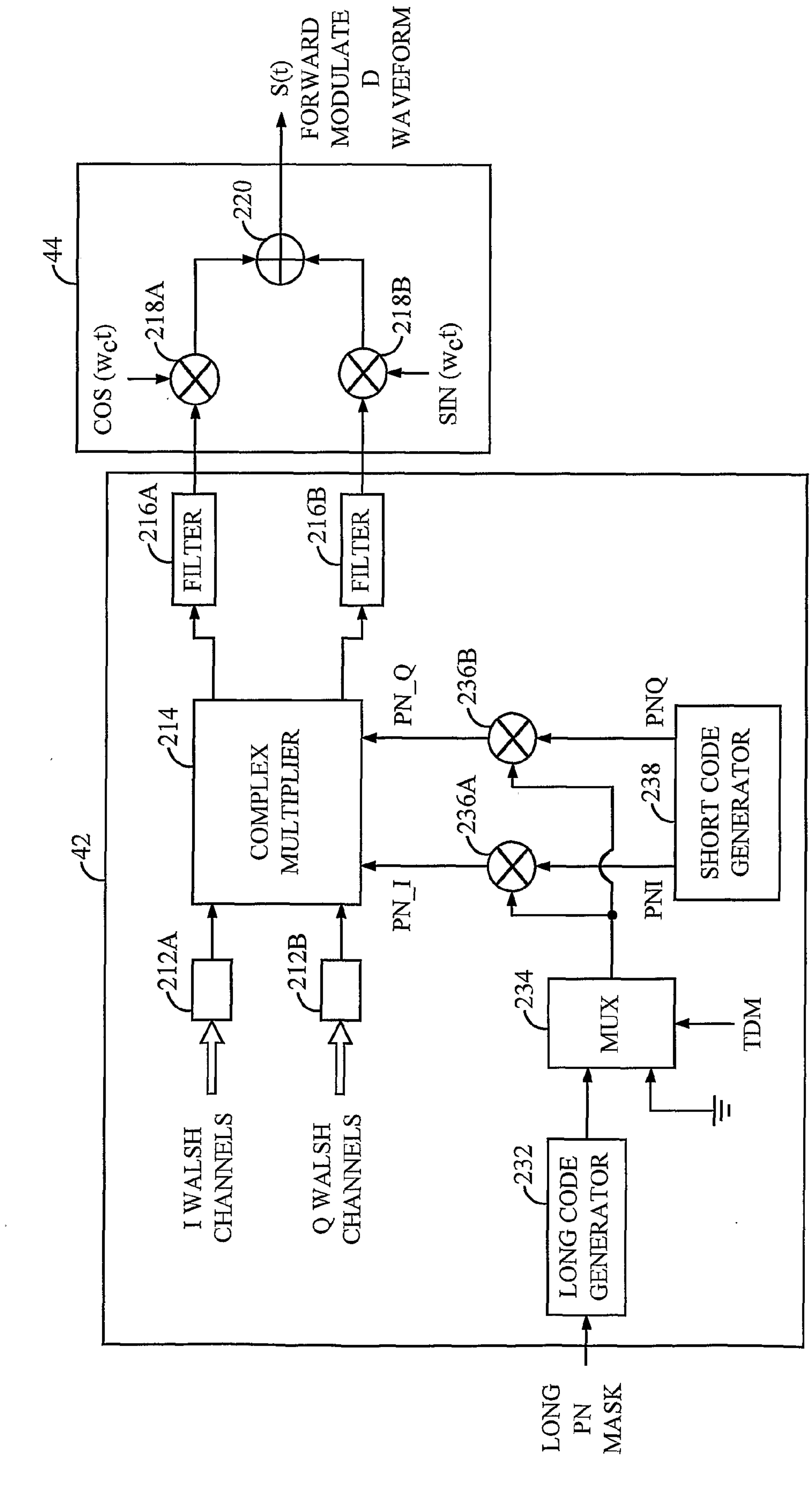
S(t)
FORWARD
MODULATE
D
WAVEFORM
44
220
218A
218B
COS (wct)
SIN (wct)
42
216A
FILTER
216B
FILTER
214
COMPLEX
MULTIPLIER
PN_Q
236B
PNQ
PN_I
236A
238
PNI
SHORT CODE
GENERATOR
212A
212B
I WALSH
CHANNELS
Q WALSH
CHANNELS
234
MUX
TDM
232
LONG CODE
GENERATOR
LONG
PN
MASK

FIG. 3B

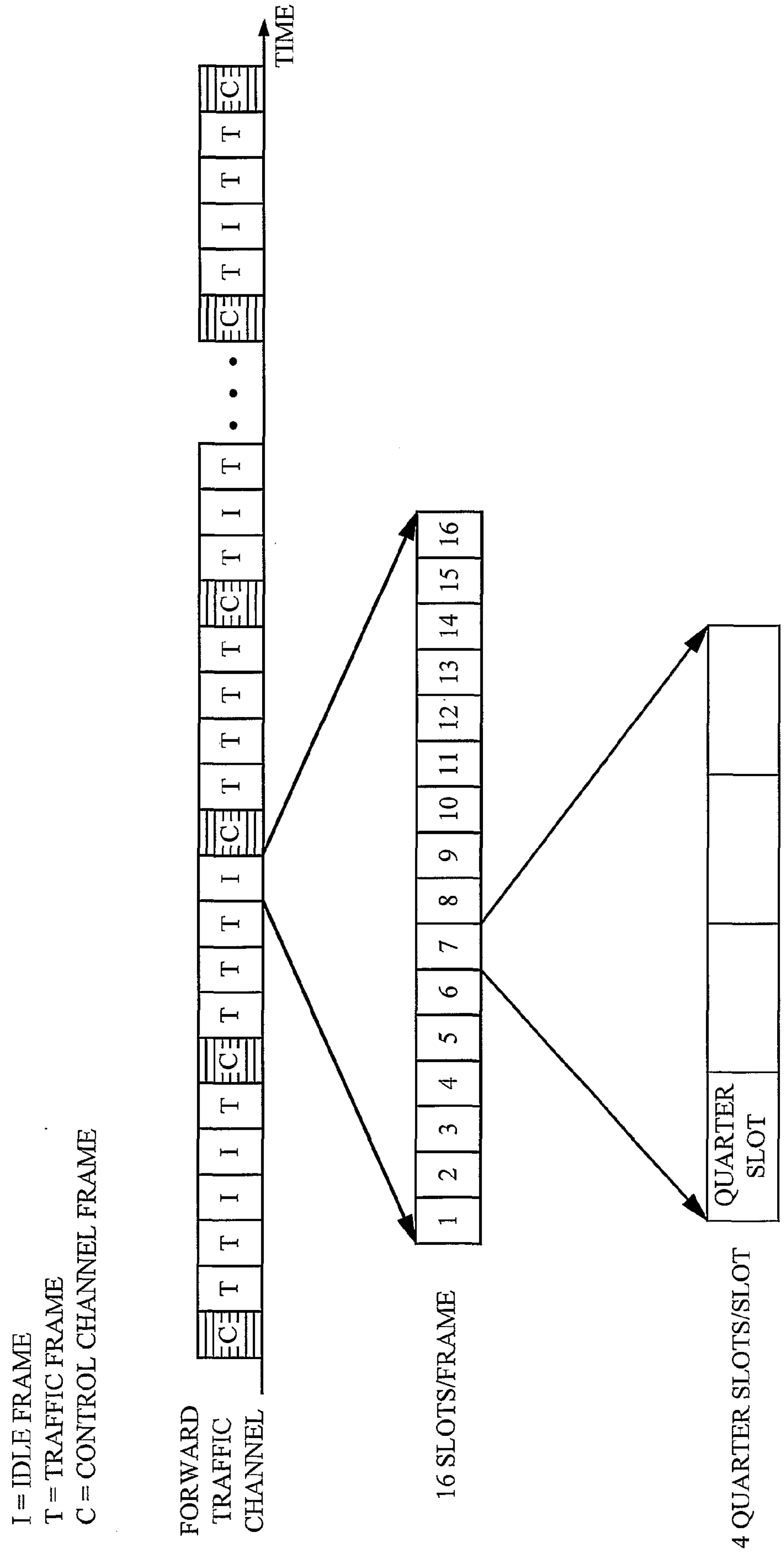
I = IDLE FRAME
T = TRAFFIC FRAME
C = CONTROL CHANNEL FRAME
FORWARD TRAFFIC CHANNEL
TIME
C T T I I T C T T T I C T T T T C T I T
C T I T T C
16 SLOTS/FRAME
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
4 QUARTER SLOTS/SLOT
QUARTER SLOT

FIG. 4A

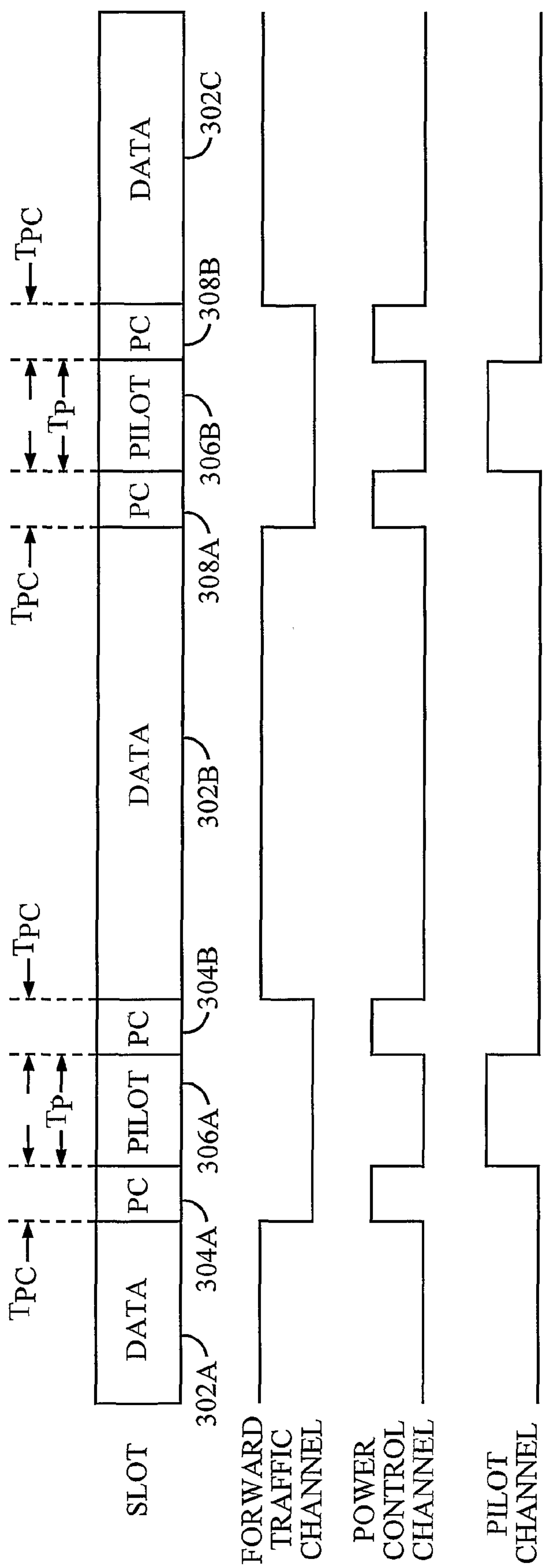
SLOT
FORWARD TRAFFIC CHANNEL
POWER CONTROL CHANNEL
PILOT CHANNEL
DATA
PC
PILOT
PC
DATA
PC
PILOT
PC
DATA
302A
304A
306A
304B
302B
308A
306B
308B
302C
T_{PC}
T_P
T_{PC}
T_{PC}
T_P
T_{PC}

FIG. 4B

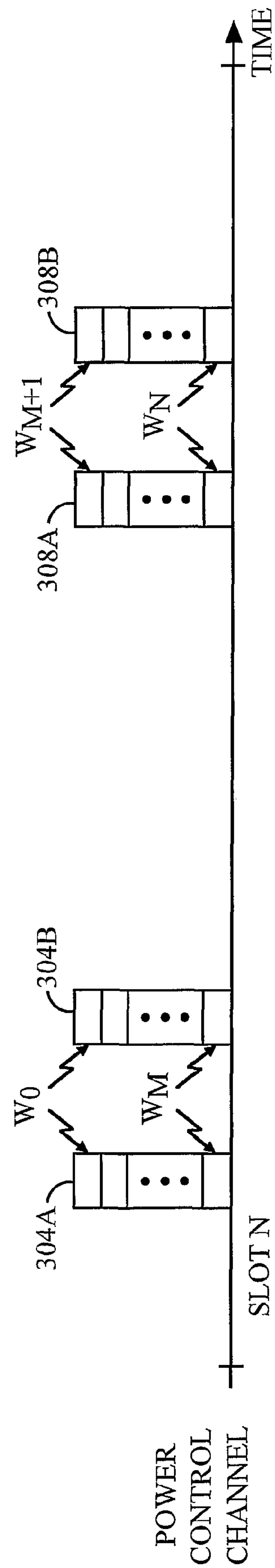
POWER CONTROL CHANNEL
SLOT N
TIME
304A
304B
308A
308B
W_0
W_M
W_{M+1}
W_N

FIG. 4C

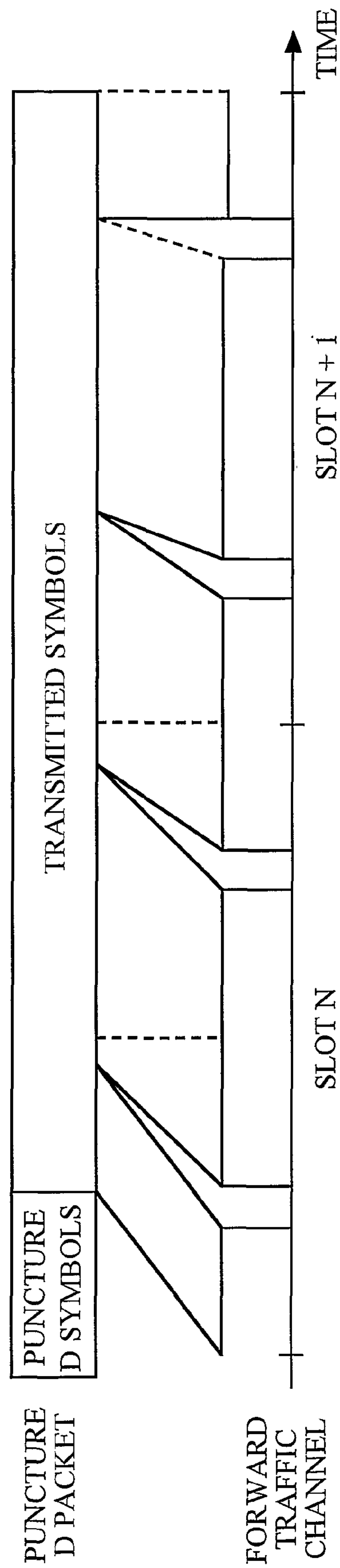
PUNCTURED PACKET
PUNCTURED SYMBOLS
TRANSMITTED SYMBOLS
FORWARD TRAFFIC CHANNEL
SLOT N
SLOT N + i
TIME

FIG. 4D

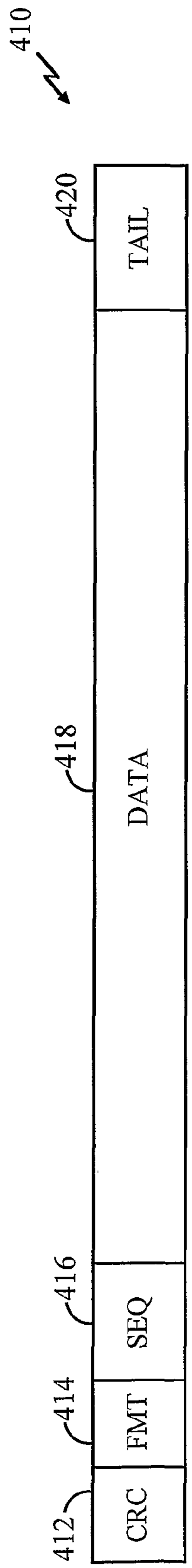

FIG. 4E

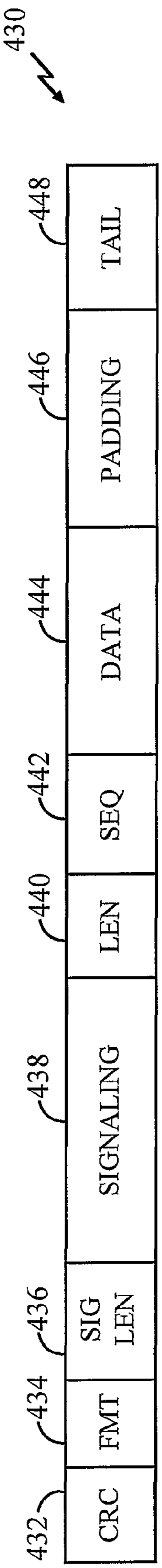

FIG. 4F

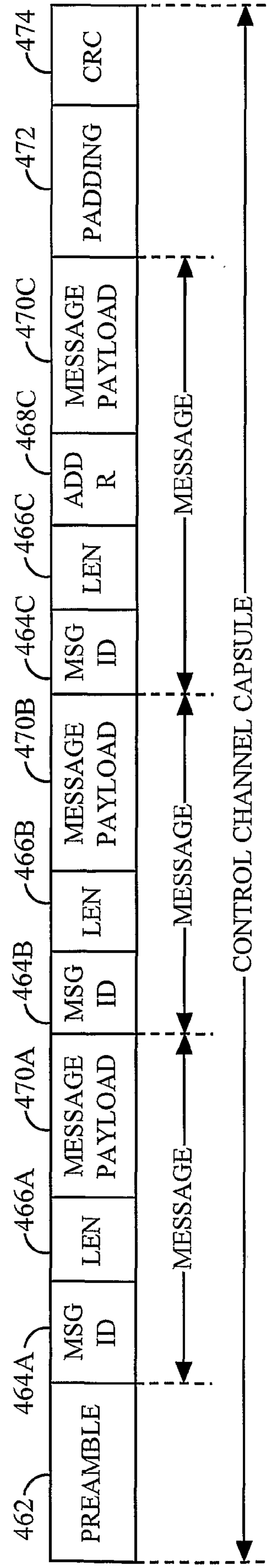

FIG. 4G

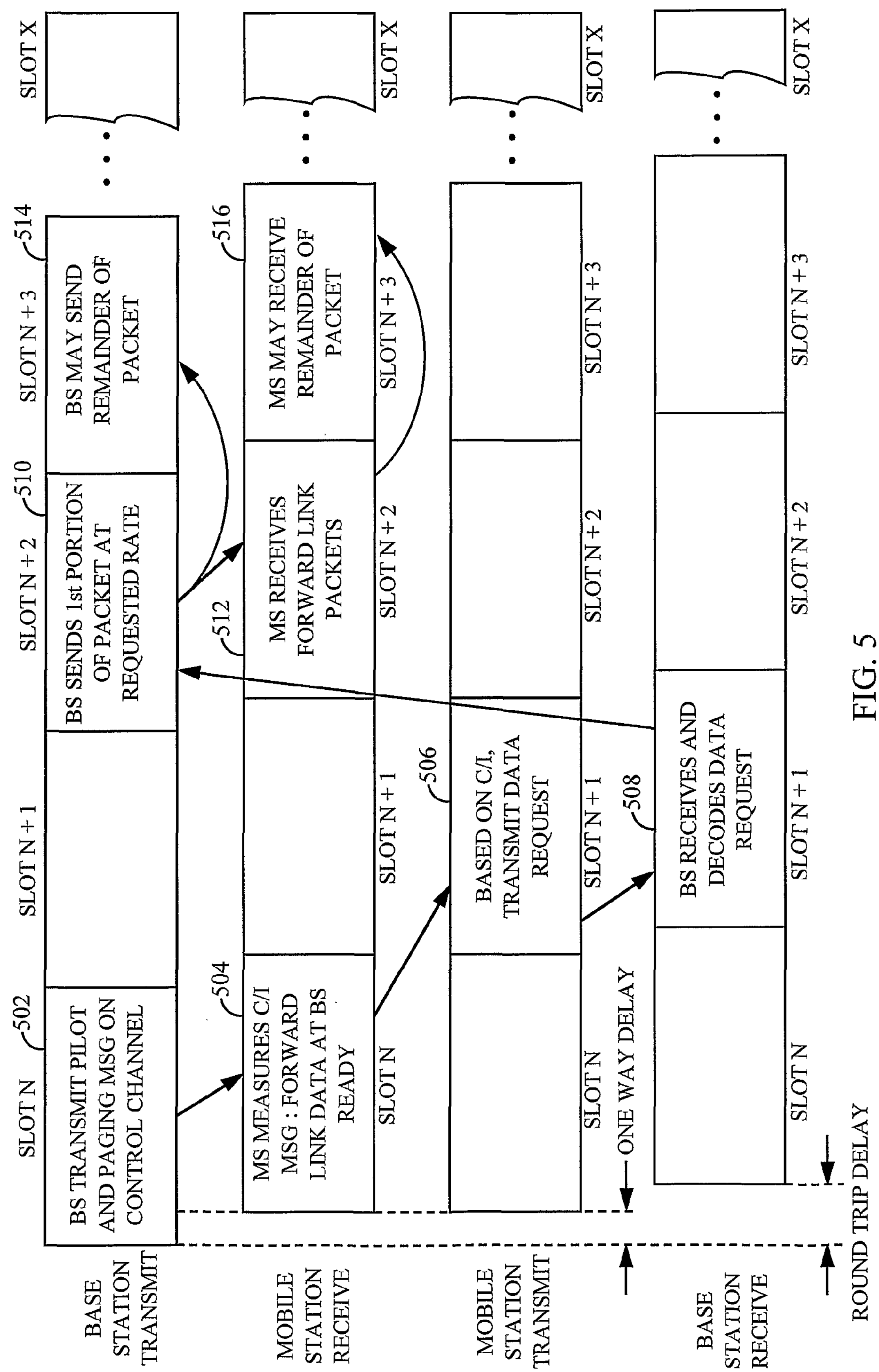
BASE STATION TRANSMIT
MOBILE STATION RECEIVE
MOBILE STATION TRANSMIT
BASE STATION RECEIVE
SLOT N
SLOT N + 1
SLOT N + 2
SLOT N + 3
SLOT X
502
BS TRANSMIT PILOT AND PAGING MSG ON CONTROL CHANNEL
504
MS MEASURES C/I MSG : FORWARD LINK DATA AT BS READY
506
BASED ON C/I, TRANSMIT DATA REQUEST
508
BS RECEIVES AND DECODES DATA REQUEST
510
BS SENDS 1st PORTION OF PACKET AT REQUESTED RATE
512
MS RECEIVES FORWARD LINK PACKETS
514
BS MAY SEND REMAINDER OF PACKET
516
MS MAY RECEIVE REMAINDER OF PACKET
ONE WAY DELAY
ROUND TRIP DELAY

FIG. 5

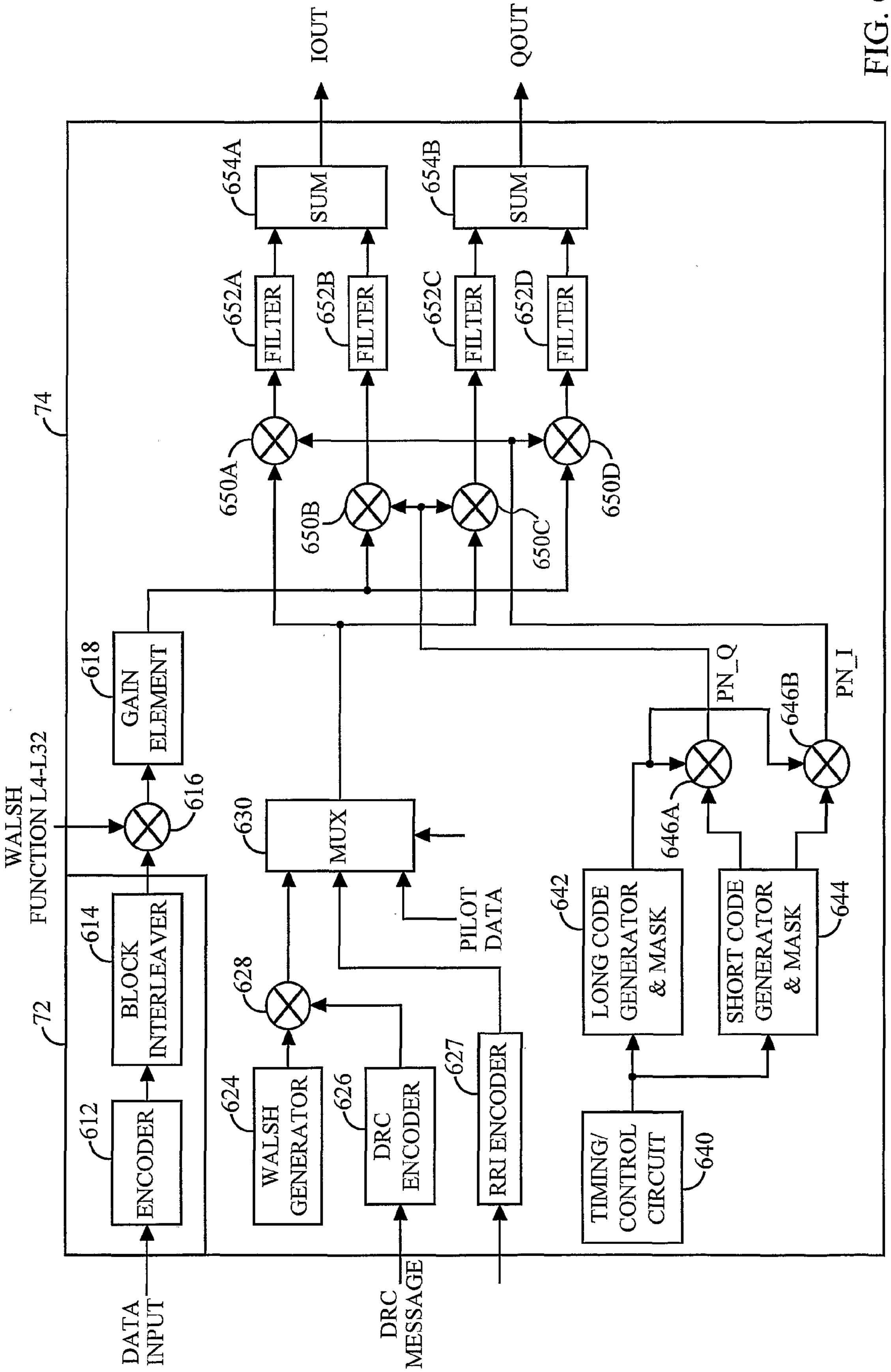
IOUT
QOUT
74
72
654A
SUM
654B
SUM
652A
FILTER
652B
FILTER
652C
FILTER
652D
FILTER
650A
650B
650C
650D
WALSH FUNCTION L4-L32
616
618
GAIN ELEMENT
612
ENCODER
614
BLOCK INTERLEAVER
630
MUX
628
624
WALSH GENERATOR
626
DRC ENCODER
627
RRI ENCODER
PILOT DATA
PN_Q
PN_I
646A
646B
642
LONG CODE GENERATOR & MASK
644
SHORT CODE GENERATOR & MASK
640
TIMING/ CONTROL CIRCUIT
DATA INPUT
DRC MESSAGE

FIG. 6

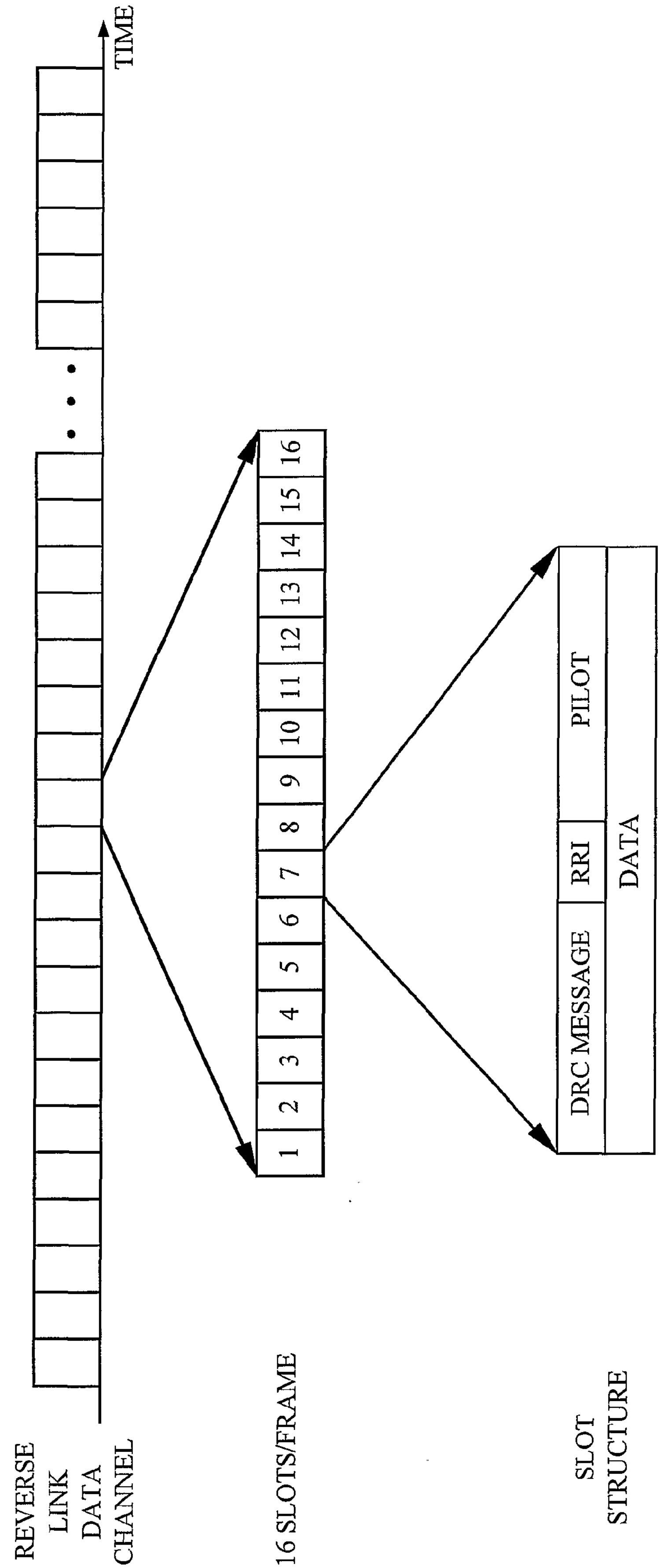
TIME
REVERSE LINK DATA CHANNEL
16 SLOTS/FRAME
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
SLOT STRUCTURE
DRC MESSAGE
RRI
PILOT
DATA

FIG. 7A

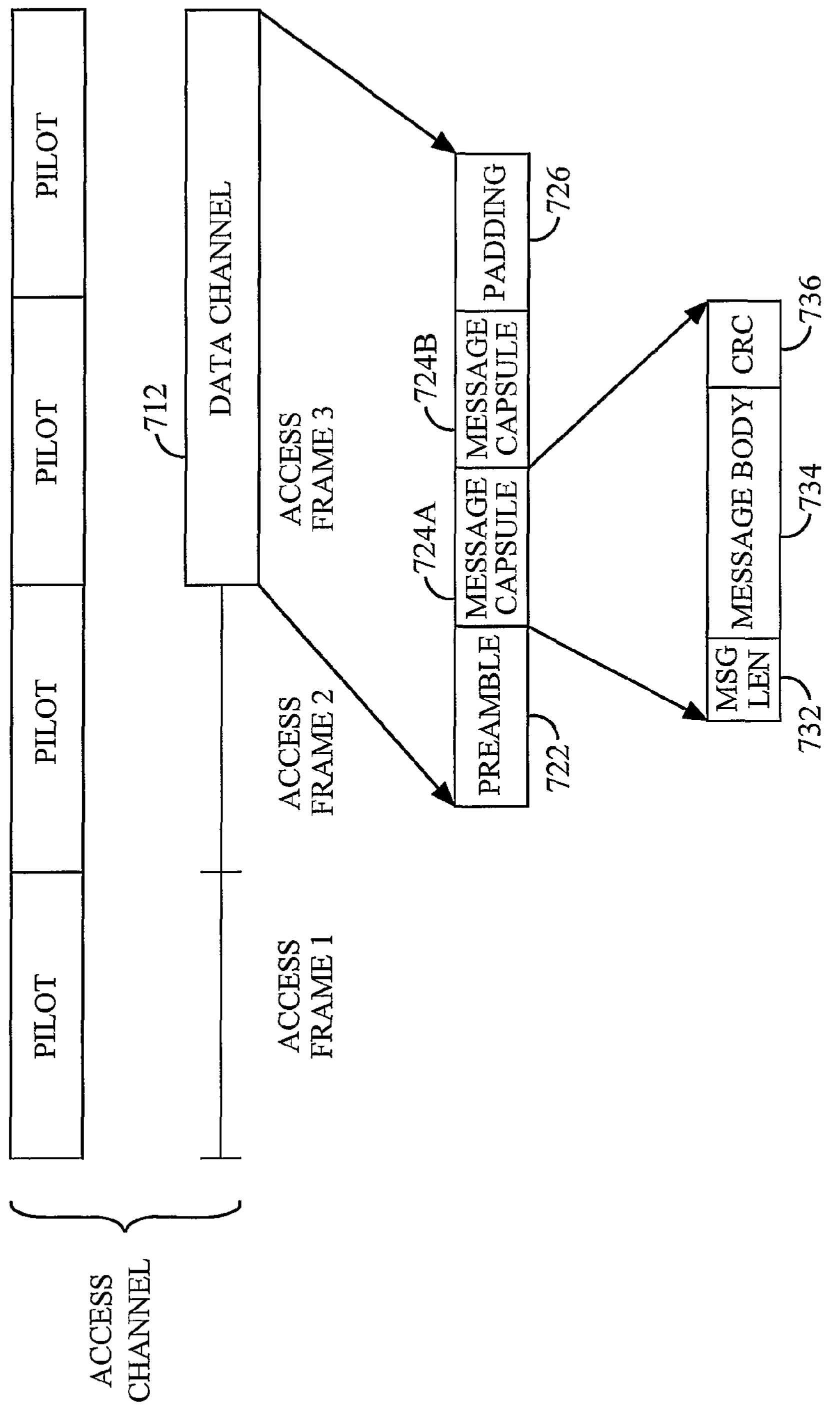
PILOT
PILOT
PILOT
PILOT
DATA CHANNEL
712
ACCESS FRAME 1
ACCESS FRAME 2
ACCESS FRAME 3
ACCESS CHANNEL
PREAMBLE
722
MESSAGE CAPSULE
724A
MESSAGE CAPSULE
724B
PADDING
726
MSG LEN
732
MESSAGE BODY
734
CRC
736

FIG. 7B

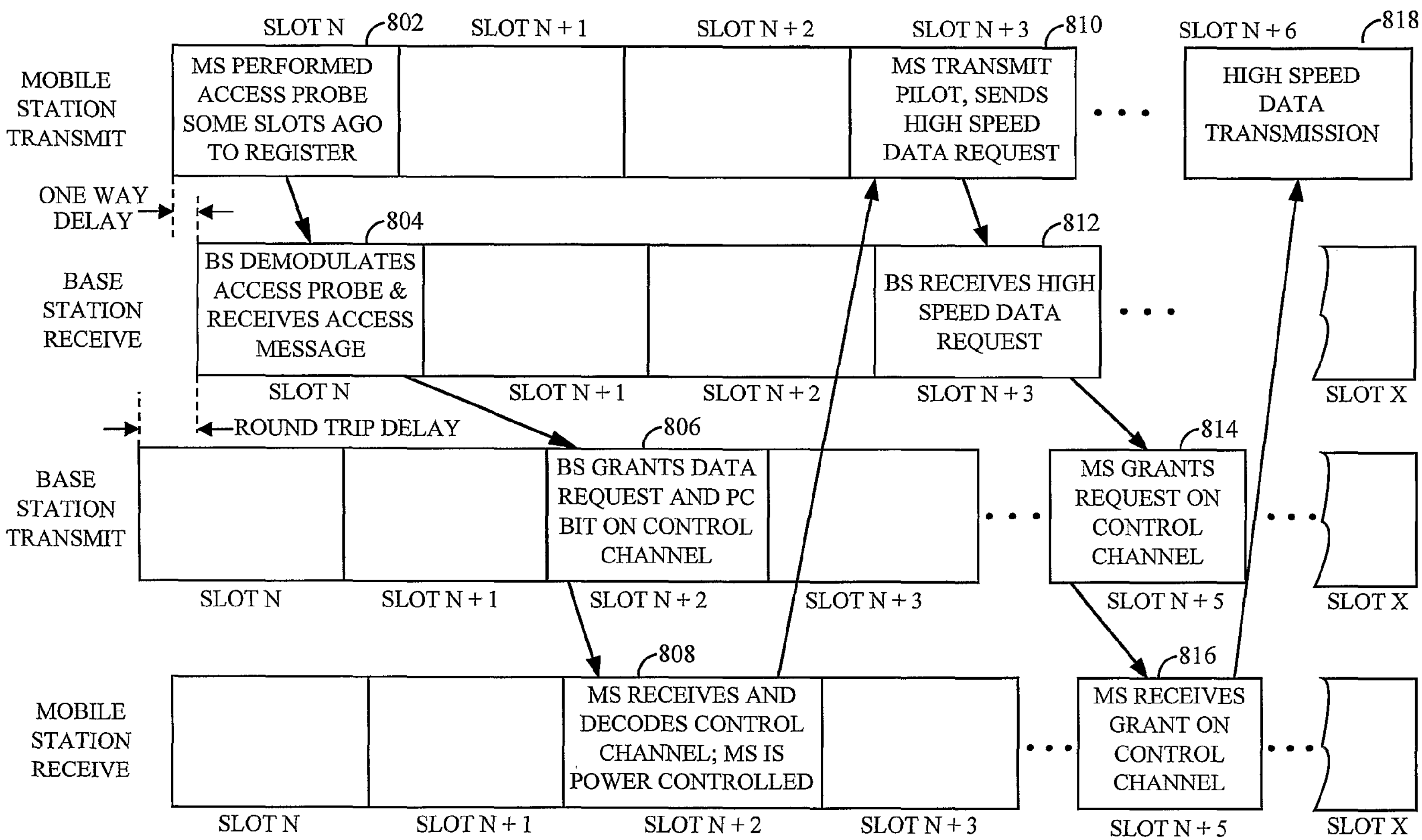
MOBILE STATION TRANSMIT
SLOT N
802
MS PERFORMED ACCESS PROBE SOME SLOTS AGO TO REGISTER
SLOT N + 1
SLOT N + 2
SLOT N + 3
810
MS TRANSMIT PILOT, SENDS HIGH SPEED DATA REQUEST
SLOT N + 6
818
HIGH SPEED DATA TRANSMISSION
ONE WAY DELAY
BASE STATION RECEIVE
804
BS DEMODULATES ACCESS PROBE & RECEIVES ACCESS MESSAGE
812
BS RECEIVES HIGH SPEED DATA REQUEST
SLOT N
SLOT N + 1
SLOT N + 2
SLOT N + 3
SLOT X
ROUND TRIP DELAY
BASE STATION TRANSMIT
806
BS GRANTS DATA REQUEST AND PC BIT ON CONTROL CHANNEL
814
MS GRANTS REQUEST ON CONTROL CHANNEL
SLOT N
SLOT N + 1
SLOT N + 2
SLOT N + 3
SLOT N + 5
SLOT X
MOBILE STATION RECEIVE
808
MS RECEIVES AND DECODES CONTROL CHANNEL; MS IS POWER CONTROLLED
816
MS RECEIVES GRANT ON CONTROL CHANNEL
SLOT N
SLOT N + 1
SLOT N + 2
SLOT N + 3
SLOT N + 5
SLOT X

FIG. 8

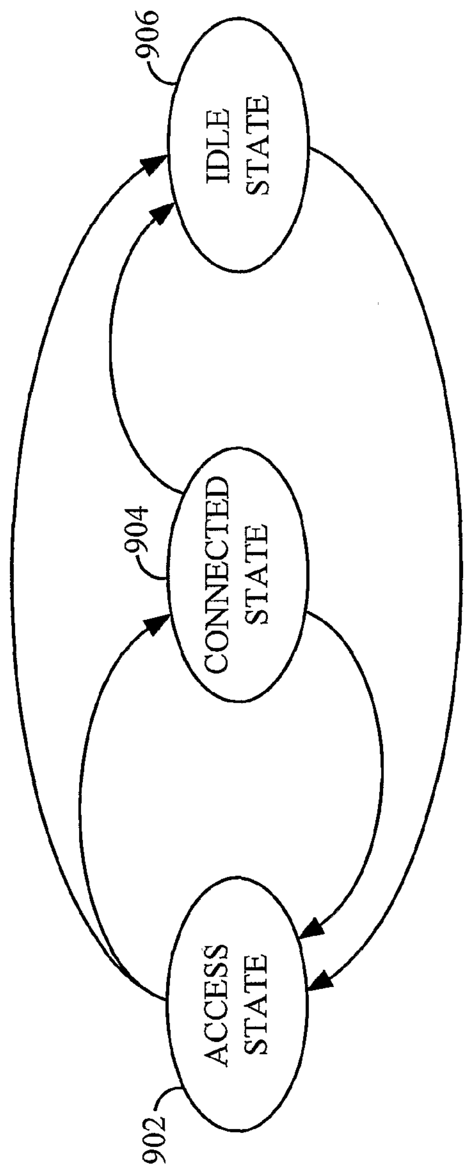

FIG. 9

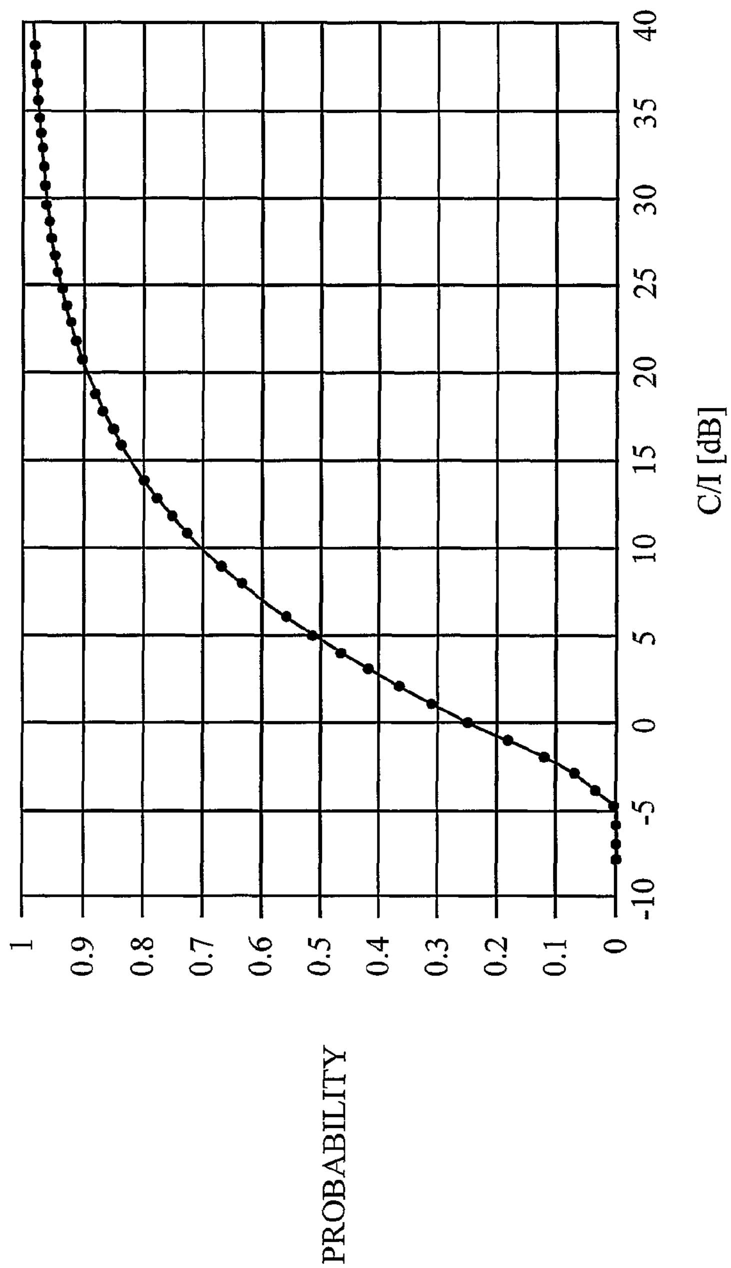
PROBABILITY
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
-10
-5
0
5
10
15
20
25
30
35
40
C/I [dB]

FIG. 10

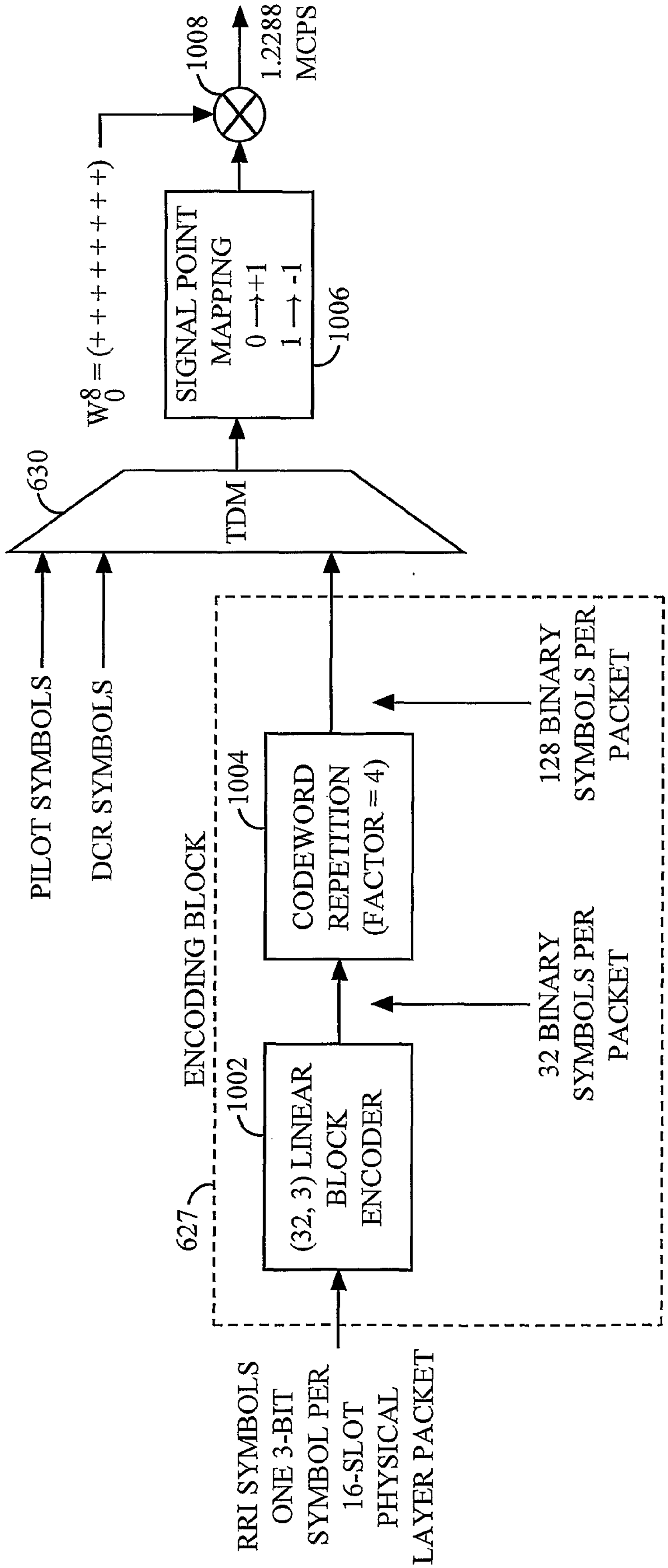
RRI SYMBOLS
ONE 3-BIT
SYMBOL PER
16-SLOT
PHYSICAL
LAYER PACKET
627
ENCODING BLOCK
1002
(32, 3) LINEAR
BLOCK
ENCODER
32 BINARY
SYMBOLS PER
PACKET
1004
CODEWORD
REPETITION
(FACTOR = 4)
128 BINARY
SYMBOLS PER
PACKET
PILOT SYMBOLS
DCR SYMBOLS
630
TDM
SIGNAL POINT
MAPPING
0 → +1
1 → -1
1006
$W_0^8 = (+ + + + + + + +)$
1008
1.2288
MCPS

FIG. 11